TASMANIAN SEAGRASS COMMUNITIES

by

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STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and to the best of the author's knowledge and belief the thesis contains no copy or paraphrase of material previously published or written by other persons except when due reference is made in the text of the thesis.

ABSTRACT

Seagrasses are marine angiosperms that grow in sheltered coastal and estuarine water bodies. They play a significant role in coastal marine ecology, and are important breeding and feeding grounds for a number of fish species. However, seagrasses are vulnerable to the impacts of some human activities through their sensitivity to reduced light energy. This may be lowered by increased turbidity and sedimentation, or the excessive growth of algal epiphytes in response to raised nutrient levels.

Five seagrass species occur in Tasmania, *Amphibolis antarctica* (Labill.) Sonder et Aschers., *Halophila australis* Doty & Stone, *Heterozostera tasmanica* (Marten ex Aschers.), *Posidonia australis* Hook. f. and *Zostera muelleri* Irmisch & Aschers., their presence or absence defining five zones around the Tasmanian coast. Most coastal areas were sampled, and seagrass beds located. When sampling these beds, the species, depth, density, substratum and presence of algal epiphytes were recorded. Using available aerial photography from three time periods (*circa* 1950, *circa* 1970 and the present), seagrass beds in selected areas were digitally mapped into a GIS database using ARC/INFO. The sample site attributes were added to the database, and patterns of distribution and change analysed and mapped.

The five seagrass species have distinct zonation patterns and distributions in relation to region, coastal formation, substratum and depth. An area of approximately 220 km^2 was mapped, leading to speculation that from 400 to 500 km^2 of seagrass may occur in Tasmania. However, the results of the analysis and mapping also indicate significant decline. Total loss has occurred in some areas. Decline is most pronounced in those parts of the State close to centres of human population and activity.

There is a strong relationship between the seagrass decline in coastal areas and the presence and abundant of algal epiphytes. Ambient nutrient levels in some coastal water bodies are likely to be a major cause of seagrass decline. In this context, this thesis proposes some mechanisms for the management and protection of Tasmania's seagrass communities, and nominates representative coastal areas for possible reserve status.

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Chapter 1
INTRODUCTION

"The demise of seagrasses is analogous to the encroachment of deserts on land..."

(Larkum *et al.* 1989, p. 823)

"It may not be until seagrass habitats have largely disappeared that we are able to understand the processes that have been responsible for their demise."

(Ward, T.J. 1989, p. 815)

1.1 Context of Study

Seagrasses are flowering plants, or angiosperms, adapted to living completely submerged in the marine environment (Robertson 1984). They grow in soft-bottomed habitats in the tidal and sub-tidal waters of sheltered and semi-sheltered coastlines in many parts of the world, including Tasmania.

Seagrasses in Tasmania have not been studied in any great detail, and there are few references to their ecology and distribution. This project is a step towards redressing this information gap. Elsewhere in Australia, and internationally, seagrasses have been the subject of increasing interest and research in recent decades (Larkum *et al.* 1989). This has arisen out of a growing awareness of their importance in the overall ecology of the coastal marine environment, and their sensitivity to human activity.

As a background to this study, this chapter looks at the ecology of seagrasses and the status of seagrasses in the context of coastal environmental management. Some case studies are reviewed in considering the causes of seagrass decline. The seagrass species found in Tasmania are described. Finally, the aims of the project and the structure of the thesis are presented.

1.2 Seagrass Ecology

The importance of seagrasses and their role in coastal ecology is discussed here. Seagrass habitat is considered in Chapter 2 (section 2.3).

1.2.1 Role of Seagrasses in coastal marine ecosystems.

Seagrasses play an important role in the ecology of estuarine and inshore marine environments. They provide a habitat for many other organisms, and the communities of which they are the major structural component show a diversity and animal abundance comparable to coral reef communities (SPCC 1978). Seagrass beds are known to have many characteristic species of flora and fauna within their communities (den Hartog, 1983). Many of these are epiphytic or epizoic. Ducker *et al.* (1977) list 105 species of algae and 20 genera of animals found growing on *Amphibolis antarctica* (Labill.) Sonder et Aschers., and May *et al.* (1978) identified 57 species of algae on species of the genera *Posidonia* and *Zostera*. The floristic and faunistic composition of the communities associated with a given seagrass species may vary between habitats.

Kirkman (1976) reviewed existing literature describing the functions of seagrasses in coastal ecosystems. In summary, these are:

(1) they are primary producers;

(2) seagrass leaves and/or rhizomes are food for a small number of primary consumers, such as garfish, swans and sea urchins;

(3) seagrasses provide a substratum for many species of epiphytes and epifauna of comparable biomass to the seagrasses themselves. These are grazed by a variety of vertebrate and invertebrate species;

(4) large quantities of detrital material are produced by seagrass beds, and this is often carried some distance from the beds themselves. This provides food for various animal species and microbes;

(5) they contributes organic matter to the sulphur cycle. Sulphate reduction fosters microbe growth important in the food chains of a variety of fish;

(6) the rhizome mats of some seagrasses bind sediments, and the leaf canopy baffles water movement. This hinders erosion, and sediments accumulate as particles settle from the slowed water. This can lead to a gradual localised raising of the sediment level (e.g. Pipe Clay Lagoon (Woodward 1985)). Fish larvae, invertebrate larvae and food particles also settle out of the water column; and

(7) juvenile fish and invertebrates are provided with protective cover from predators.

There are additional functions. The baffling action of seagrass leaves and the shelter they provide from predation both contribute to the greater populations and diversity of species in seagrass beds (Kennish 1986). Also, the rhizome mats of some species, such as *Posidonia australis* Hook. f. will continue to hold sediments together long after the death of the seagrasses themselves, and provide a substratum for macroalgal growth (V. Neverauskas 1992, pers comm.). And finally, the considerable quantities of dead seagrass leaves that are washed up on some shorelines trap wind-blown sand, and may play a part in dune formation.

1.2.2 The structure of seagrass communities

Although seagrasses themselves form the major structural component in seagrass communities, they are only one element in a highly complex ecosystem. For example, den Hartog (1983), argued against a common view of seagrass communities being "*simple-structured, monodominant systems*" (p. 6). He identified sixteen separate structural elements in temperate *Zostera marina* L. beds (Table 1.1).

Table 1.1:
Structural elements in a temperate *Zostera* bed
(after: den Hartog 1983, p. 7)

(1) The seagrass itself
(2) Epiphytes on the seagrass
(3) Algalfilm on the bottom substrata
(4) Mat of loose-lying entangled algae
(5) Endophytes
(6) Immobile epifauna
(7) Free-moving epifauna
(8) Immobile fauna on the bottom
(9) Free-moving fauna on the bottom
(10) Free-moving fauna on the loose-lying algal mat
(11) Infauna
(12) Free-swimming animals, not confined to a special part of the community
(13) Temporary residents
(14) Phytoplankton
(15) Zooplankton
(16) Microbial communities

Epiphytes play an important role in seagrass communities, and only develop the potential to smother the seagrasses where unnatural nutrient loads are present. In these conditions, it is other marine algal species and not specialised seagrass epiphytes which are involved (den Hartog 1983).

Temperate seagrass beds tend to contain only one seagrass species (den Hartog 1983), and this is generally true of seagrasses in Tasmania. In some locations in Tasmania, however, seagrass beds are mosaics of two or more species occuring in adjacent small monospecific patches, sometimes of only a few square metres in area. Elsewhere, two or more species may occur in narrow monospecific bands along a shoreline, apparently zoned according to depth, or interspersed with species of macroalgae.

1.2.3 The role of seagrass communities in the ecology of fish

It is clear from the previous discussion that seagrass beds are complex and productive ecosystems in the inshore coastal environment, and that they provide many different niches for the development of a wide variety of flora and fauna. Howard *et al.* (1989) summarised research on faunal assemblages of seagrass communities, and Bell and Pollard (1989) reviewed the ecology of fish assemblages associated with seagrasses, and it is largely from these works that the following points are drawn.

There are many gaps in our understanding of the ecology of the majority of faunal species in Australian seagrass beds. Most research has focussed on species of importance to commercial fisheries. The complex communities on which these species depend are poorly understood, even though it is the smaller invertebrates at lower trophic levels that may be most vulnerable to environmental change. The management of seagrass communities therefore requires a much better understanding of their associated faunas.

Generally it can be said that the flora and fauna in a seagrass community are more adapted to the local set of environmental parameters than to a particular species of seagrass. Few fauna species are restricted to a single seagrass species (Howard *et al.* 1989). Even some pipefish (Syngnathidae), highly adapted to seagrass habitats, may occur among seagrasses of more than one species (Howard & Koehn 1985).

Some species of fish prey on seagrass fauna, but are not the only, nor necessarily the most significant predator in seagrass ecosystems. Because of the protection offered by the seagrass leaves, the levels of predation are usually less than on surrounding unvegetated areas. Larger crustaceans and wading birds may be equally important predators and have a significant impact on some invertebrate species.

Bell and Pollard (1989) distilled from the literature the key points relating to seagrasses and their associated assemblages of fish. These are:

(1) fish in seagrass beds are more diverse and abundant than over adjacent unvegetated areas. In Tasmania, for example, Last (1983) found a greater diversity of species in seagrass fish assemblages than in those on unvegetated sediments;

(2) the amount of time and the phase of life cycle spent associated with seagrass varies for different fish species;

(3) seagrass beds are important nurseries for the larvae of many fish species which settle directly from the plankton. Fish rarely spawn in seagrasses. The larvae obtain food and shelter in their early, vulnerable growing phases, and then move on to other coastal habitats;

(4) fish are rarely primary consumers in seagrass beds, but usually feed on crustaceans on the seagrasses and in the plankton;

(5) the location of fish in the seagrass canopy varies between species;

(6) the time of day, and the nature of the surrounding habitat influences the fish present; and,

(7) fish assemblages from adjacent seagrass habitats are often not similar.

Fish spend different periods of time associated with seagrasses. There are seasonal arrivals and departures from the seagrass community, and there are species that frequent seagrass beds at certain times of day or tidal phase. Also, Fish that are found associated with seagrasses tend to be either smaller species than those on bare sediments, or juveniles of larger species.

Although few adult fish depend greatly on seagrasses for food or shelter, seagrasses provide the principal shelter for juvenile fish in many estuaries, without which the numbers of fish surviving juvenile stages would be greatly diminished (Bell *et al.* 1987). Although it is unusual for a fish species to eat fresh seagrass leaves, in south-eastern Australia both the southern seagarfish *Hyporhamphus melanochir,* and the rock flathead *Platycephalus laevigatus* are examples of species that rely on seagrass leaves for much of their carbon source (Nichols *et al.* 1985). The luderick *Girella tricuspidata* feeds similarly. The seagrasses of that same region are host to many leatherjackets that take bites from seagrass leaves to obtain encrusting fauna and epiphytes.

The location of a seagrass bed in a bay or estuary may affect the abundance of fish present. Different species settle in different parts of an estuary. The patchy settlement of larvae and their subsequent distribution within the seagrass beds also influence the abundance and species composition of seagrass fauna (Bell & Pollard 1989).

Fish populations in estuaries have been shown to decrease with the loss of seagrasses, but this is not always the outcome of seagrass decline. Many fish species spawn at the mouths of estuaries which means their larvae may well not settle in that particular estuary. Conversely, those larvae settling in a given area may have come from far afield. Seagrasses may thus have to decline extensively in a region before the impact on fish populations is recognised.

In summary, it can be seen that seagrass communities play an important role in the ecology of marine and estuarine coastal waters. Much is still unknown of the complexities of the interrelationships between the flora and fauna in these communities, and it is important that the focus of research is not merely on their importance to commercial fisheries.

1.3 Seagrasses and coastal management

A range of land and water based human activities in the coastal zone and related catchments have the potential to affect adversely the diversity of marine flora and fauna through discharges of by-products and wastes. In order to protect the marine environment it is therefore important that a coastal zone approach is adopted to manage jointly any human activity both on land and in adjacent marine areas (Salm & Clark 1984).

Many classes of pollutant have an impact on the marine biota, which may include organisms in seagrass communities, and seagrasses themselves. Amongst these substances are herbicides, pesticides, antifouling paints and agents, petroleum hydrocarbons, phosphates and nitrates from sewage, detergents and fertilisers, heavy metals, and surfactants and dispersants. Additionally impacts are caused by sedimentation and turbidity, discharges of high or low temperature water, and runoff or discharge of high or low salinity water (Kenchington 1990).

1.3.1 Seagrasses as environmental indicators

Because seagrasses are among those types of marine and intertidal vegetation that are sensitive to pollution or its side-effects, and to catchment modification and coastal engineering, they are now regarded as important indicators of the health of the marine coastal environment. For example, a report to the government of Victoria (VIMS 1991) argues for the ongoing monitoring of seagrass communities, as one of a suite of 'Key Indicators' of the marine biota. The concept of 'Key Indicator' refers to species for which any change in health, abundance or distribution might indicate a possible wider change in the complex ecological systems of which they are part (VIMS 1991).

The Victorian report lists a range of marine and coastal activities and processes which may have adverse impacts on the environment (VIMS 1991). Some of these were considered to have a direct and significant influence on both water quality and the marine biota of which seagrasses are an important component. These include the construction and operation of port and marina facilities, recreational activities, commercial fishing, catchment use, outfalls, and short term natural processes such as storms . The report states:

"Loss of seagrass would be expected to modify the abundance of fish, including a number that are important components of recreational catches, and also influence directly or indirectly the abundance of various invertebrate species. Seagrasses are thus biologically important and politically sensitive" (VIMS 1991 p. 29).

Two examples of pollutants that impact on seagrasses or the faunal assemblages of seagrass communities are nutrients and heavy metals. The effects of increased nutrient loadings are discussed in some detail below (see Section 1.4). Here the effects of metal pollution on seagrass communities are considered briefly.

Because seagrasses have a strong baffling effect on water movement there tends to be a high rate of sedimentation in seagrass beds. The beds thus tend to accumulate higher levels of metals and organic materials than adjacent habitats (Ward 1989). At least a proportion of the metals in the shallower sediments of seagrass beds are biologically available, which includes uptake by seagrass root systems. Seagrasses are bioaccumulators of metals, that is they absorb and partly retain metals from the surrounding environment. Also, they are to some extent bioconcentrators of metals in their tissue (Ward 1989).

The levels of metals in the leaves of seagrasses have been shown to relate significantly to the concentrations in the sediment and the water column. In the Netherlands and Denmark *Zostera marina* has been used to monitor the levels of Cadmium, Zinc and Lead in the marine environment, and there is strong evidence that *Posidonia australis* could be used as a 'sentinel accumulator' of metals in Australian temperate coastal waters (Ward 1989)

Seagrasses themselves seem to be little affected by high levels of metals in the environment, and they are not ideal as indicator species for the impact of metals. However, some species of fauna associated with seagrass communities have significantly reduced populations at contaminated sites. At Port Pirie in South Australia the number of species of fauna, in particular fish, was reduced as contamination increased. The composition of species also changed (Ward 1989).

1.3.2 Seagrass habitat protection

Seagrass communities can best be protected through the establishment and enforcement of strict controls on pollution discharges (especially nutrients) and activities that increase sedimentation. Any specific protection granted to seagrass communities in the form of reserves or habitat of special significance is of limited value unless pollution from adjacent catchments is eliminated, or at least controlled. Bell and Pollard (1989) argue that if resources are scarce they are better spent on controlling the processes that lead to seagrass decline than on other means of protection. However, reserve status is of value in increasing management options, in reducing the risk of mechanical damage by fishing operations, and in raising public awareness of the ecological importance of seagrass communities.

Two possible mechanisms for protecting seagrasses are their declaration as wetlands, and their inclusion in Marine and Estuarine Protected Areas (MEPA).

1.3.2.1 Wetlands

A number of definitions of the term Wetland are used in the literature, and some of these include permanently submerged marine and estuarine areas. Arthington and Hegerl (1988) include vegetated and unvegetated areas to a depth of three metres below low water spring tide level, and seagrasses surveyed in NSW by West *et al.* (1985) were included as coastal wetlands by Pressey and Harris (1988). In Tasmania, intertidal and sub-tidal communities were included in a reference to coastal wetlands by Kirkpatrick and Tyler (1988).

Australia is a signatory to the Ramsar *Convention on Wetlands of International Importance Especially as Waterfowl Habitat* (Anon. 1975). This convention classifies wetlands of all types and included a number of subtidal and tidal habitats that suitable for seagrasses. These are described in the Convention as 'Marine and Coastal Wetlands', from which potential seagrass habitats are listed below.

(1) marine waters - permanent shallow waters less than six metres deep at low tide; includes sea bays, straits;

(2) subtidal aquatic beds; includes seagrasses, tropical marine meadows;

(3) estuarine waters; permanent waters of estuaries and estuarine systems of deltas;

(4) intertidal mud, sand or sand flats;

(6) intertidal marshes, and tidal brackish marshes; and

(7) brackish to saline lagoons with one or more relatively narrow connections with the sea (Anon. 1975).

Australia signed the Convention without reservation in 1974, and it came into force on 21 December 1975. The Agreement's aim is to promote the conservation of wetlands and waterfowl, and to provide for their protection and stewardship. A number of wetlands in Tasmania have been listed, although at present no specific areas of seagrass habitat have been included. The Ramsar Convention does not legally bind governments to prevent ecological damage to wetlands. Nor does it offer strict protection to declared areas, but rather fosters a policy of 'wise use' (Kriwoken & Haward 1991). Its value in conservation is therefore limited, although its use as a tool in the protection of seagrass habitat has not been tested in Tasmania.

1.3.2.2 Marine and Estuarine Protected Areas (MEPA)

Marine reserves in Tasmania can be proclaimed under the State's *National Parks and Wildlife Act* (1970), although changes to the Act in 1992 may require the approval of both houses of Parliament to create a MEPA in future. Fishing activities within a declared marine reserve can be controlled under regulations of the *Fisheries Act* (1959). Since the Offshore Constitutional Settlement in 1979 and its enabling legislation the *Coastal Waters (State Powers/State Title) Acts* (1980), only the Commonwealth Government has power only to protect the sea and seabed outside a three nautical mile boundary from the low water mark (Kriwoken & Haward 1991). Since seagrasses are almost wholy contained within that boundary, Commonwealth jurisdiction is not relevant to seagrass protection in Tasmania.

Prior to 1991, Tasmania had 15 MEPAs principally for the protection of habitat for wading birds, and 10 further wetlands with the limited protection offered under the RAMSAR convention. Marine habitats and ecosystems were not protected.

Coastal areas in Tasmania were surveyed in 1981 and 1984 to select suitable sites for establishment as marine reserves (Edgar 1981, 1984b). It was proposed that representative reserves for each biogeographic province should be protected (Edgar 1984b). In 1989 these studies were used in conjunction with guidelines from the I.U.C.N. on MEPAs (Kriwoken & Haward 1991). In the initial phase of the Tasmanian program, four reserves containing representative Maugean inshore marine communities were identified for declaration. These are located on the east and south east coasts, and include three small areas of scientific or recreational interest (Governor Island off Bicheno; Ninepin Point and Tinderbox in the D'Entrecasteau Channel), and one larger area on the western coastline of Maria Island. This reserve was to include Chinamans Bay which provides habitat for significant areas of *Amphibolis antarctica* and *Heterozostera tasmanica* (Martens ex Aschers.). During the consultation process Chinamans Bay was excluded from the reserve due to pressure from recreational fishing interests. This was conditional on suitable substitutes being found elsewhere. It is hoped that this study will facilitate the identification of a number of such areas.

1.4 Seagrass Decline

1.4.1 Case studies

Although prior to this project no work had been done in Tasmania looking at changes in seagrass distribution, there have been a number of studies elsewhere in Australia. These have documented the decline of seagrasses in particular areas, and have attempted to provide causal explanations linking this loss to natural and human activities. These areas include Cockburn Sound in Western Australia, the eastern shore of Gulf St. Vincent off Adelaide and its suburbs in South Australia, Western Port in Victoria, and Botany Bay in New South Wales.

In reviewing these case studies and the causes they suggest for seagrass decline Shepherd *et al.* (1989) proposed a "*unifying hypothesis*" to explain seagrass loss, namely:

". . *that a reduction in the light reaching seagrass chloroplasts precludes effective seagrass photosynthesis*".

Such a reduction can occur through

". . *increased turbidity arising from living or non-living particulates in the water, or increased shading by the deposition of silt or the growth of epiphytes on leaf surfaces or stems*" (Shepherd *et al.* 1989, p. 382).

Other mechanisms may be involved in specific cases. These may include: overgrazing of seagrasses by urchins, the relationship between epiphytes and the epifauna grazing on them, the effects on the populations of epifauna from nutrient rich and/or toxic effluents, a disruption to carbon and nutrient uptake by seagrass leaves by sediment deposition and epiphytes, changes in the redox potential of sediments, and effluents in the water column that are toxic to the seagrasses themselves (Shepherd *et al*. 1989).

In a number of cases, once the loss of seagrass has begun, the decline has become self-perpetuating. This process has been termed "*auto-catalytic*" by Larkum (1976). Examples of such auto-catalytic decline occur in the case studies below.

In some cases of decline, the naturally occurring blowouts that occur in seagrass beds in some regions have become a focus of the dieback. These blowouts usually migrate towards the prevailing swell, the bare sediment being recolonised at the same rate it is being exposed at the other edge of the bed (Clarke & Kirkman 1989). In Holdfast Bay, South Australia, the blowouts are reworked on average every 95 years under normal conditions, but in recent decades have shown an autocatalytic decline (Shepherd *et al.* 1989).

The following case studies are only briefly outlined, but lend support to the central hypothesis concerning seagrass decline proposed by Shepherd and his co-authors. They may also indicate possible causes of decline in Tasmanian seagrasses.

1.4.1.1 Cockburn Sound - Western Australia

Over a 16 year period from 1962 to 1978 around 97% of the seagrass meadows were lost from Cockburn Sound (Cambridge & McComb 1984). The species found in the Sound include four of the genus *Posidonia,* and two of the genus *Amphibolis.* Some possible causes for the decline were suggested and/or investigated, but rejected. These included disease, local salinity change, temperature change and altered water movement (Shepherd *et al.* 1989). More likely causes stemmed from the heavy industrial development which had occurred on the shores of the Sound, commencing in the mid 1950's and coinciding with the onset of seagrass dieback. These industries include a steel mill, an oil refinery, a superphosphate plant, an ammonium nitrate plant and other metal industries. Additionally, a sewage treatment works at Woodman Point towards the north of the Sound began discharging waste in the mid 1960's. The greatest rate of loss occurred from 1969 into the 1970's, coinciding with a considerable rise in the levels of nitrogen entering the water column.

It was shown that the increased nutrients entering the water were enhancing the growth of epiphytic algae on the seagrass leaf surfaces (Silberstein *et al.* 1986). The epiphyte cover is expressed as chlorophyll a ($\mu g\ cm^{-2}$ leaf area). When corrected to allow for the lower epiphyte load on new leaf growth, the light had been reduced by 63% in deteriorating beds and only 35% in healthy beds (Shepherd *et al.* 1989). Similar 'loose-lying accumulations of filamentous algae' to those found on thinning seagrasses in Cockburn Sound were also a common occurrence in this study of Tasmanian seagrasses in many of the bays and estuaries close to human habitation (see Chapter 6).

1.4.1.2 Western Port - Victoria

Another case of catastrophic seagrass decline has been monitored in this large coastal inlet 50 km south of Melbourne opening into Bass Strait. Western Port has an area of 680 km^2, 37% of which was covered with seagrass and macroalgae in the early 1970's (Bulthuis 1981). The dominant species was *Heterozostera tasmanica,* with *Amphibolis antarctica, Zostera muelleri* Irmisch & Aschers. and various macroalgal species, principally *Caulerpa cactoides,* also present in large stands.

By 1984 the area covered by these plants had reduced from 250 km^2 to 72 km^2 , a loss of 71%. The greatest decline was in the *Heterozostera tasmanica* beds where some 90% was estimated to have disappeared (Shepherd *et al.* 1989). Other species showed a much lower decline. The dieback was most evident on the intertidal mudflats which became denuded of vegetation, with those stands in the sandy dendritic channels from the most part surviving, albeit suffering from a loss in biomass per unit area.

The potential causes of the decline, as in Cockburn Sound, were many. The land surrounding Western Port has been subject to agricultural, industrial and urban development, with attendant runoffs. The waterways experience recreational, fishing and shipping activities. However, because water bodies elsewhere in the state have a greater level of these activities and developments yet still sustain healthy populations of *Heterozostera tasmanica* (eg. Corio Bay), an explanation for the decline in Western Port had to be sought elsewhere.

The seagrasses in Western Port were seen to collect a fine coating of mud on their leaves due in part to an increased level of suspended solids in the water. This mud coating blocks out the light and thus reduces photosynthesis. It has been hypothesised that the reduction in light and the higher temperatures experienced by the seagrasses on the intertidal mudflats combine to overstress them, causing their death. Seagrasses in the channels are exposed to swift currents which prevent the mud from adhering. Once the mud banks become denuded of seagrass they are subject to erosion which further increases the suspended solids in the water, thus the process becomes self-perpetuating and the dieback continues (Shepherd *et al.* 1989).

This autocatalytic mechanism has not been fully tested, and undoubtedly other secondary factors have contributed to this example of seagrass loss.

1.4.1.3 Gulf St. Vincent - South Australia

The eastern shore of the Gulf St. Vincent provides a semi-sheltered shallow habitat colonised by extensive beds of seagrass. The rapid development of the coastline in the region of Adelaide and its northern and southern suburbs, with the attendant increasing discharges of industrial and sewage wastes has had considerable impact on these seagrass communities in the last few decades. This decline has been well documented in studies such as Shepherd (1970), Steffensen (1979), and Neverauskas (1985a, 1985b, 1987a, 1987b). Over 5 000 hectares had been lost by the middle 1980s between Marino further south and

Bolivar to the north of Adelaide.

Three species of the genus *Posidonia* are found in this region, *P. angustifolia* Cambridge & Kuo, *P. sinuosa* Cambridge & Kuo and *P. australis* (of which only *P. australis* is found in Tasmanian waters). These, plus *Amphibolis antarctica*, occurred to depths of 15 m, with *Heterozostera tasmanica* dominating the intertidal flats in the northern part of this section of coast (Shepherd *et al.* 1989).

The patterns of seagrass decline in some places closely mirror the dispersal patterns of the sewage sludge from outfalls at Port Adelaide and Glenelg, and Fork Creek at Bolivar. A similar pattern was documented around a cannery waste outfall at Port Lincoln. These losses have been attributed to the combined factors of nutrient induced epiphytic growth, plus increased sedimentation and turbidity due to ongoing seagrass loss. This secondary mechanism appears to be responsible for the continuing decline. Coastal engineering works such as the Outer Harbour breakwater, pipeline construction for the Port Adelaide sewage outfall and marina construction at North Haven have also caused losses due to sedimentation and increased turbidity.

1.4.1.4 Botany Bay - New South Wales

Botany Bay is a coastal embayment of approximately 4 600 ha situated immediately south of Sydney. It is surrounded by considerable industrial, residential and commercial development, including an oil refinery and Sydney's international airport. The Georges River also flows into the bay. There is a high level of nutrient enrichment of the water from sewage disposal and urban runoff, and parts of the bay have been dredged regularly to facilitate the movement of large ships.

Posidonia australis, *Halophila ovalis* (R. Brown) Hook. and *Zostera capricorni* Aschers. are seagrasses found in Botany Bay, and their changing distribution has been studied by Larkum and West (1983) and discussed by Illert and Reverbi (1986). The stands of *Posidonia australis* had by 1986 lost about 58% (257 ha) of the area they covered in 1942, being replaced in places by *Zostera capricorni*. By 1987 the continuous bed of *P. australis* had been reduced to a number of fragments (Larkum & West 1990). Changes were detected using historical aerial photography spanning the years 1930 to 1985, field observations, and sediment coring to detect old *P. australis* root mats.

The factors considered responsible for this decline include: high nutrient levels entering the bay from the Georges River and elsewhere causing increased epiphyte growth; dredging of the bay's mouth, leading to increased wave action and sediment erosion; two severe storms in the 1970's to which the beds were now more vulnerable; and, an increase in the population of the sea-urchin *Heliocidaris eryhogramma* which grazes on the seagrass (Shepherd *et al.* 1989).

1.4.2. Causes of seagrass decline

The case studies above and other research suggest a number of processes attributable to human activity by which seagrass beds can be reduced in size and health, or destroyed completely. It is useful to summarise these and other agents that can cause damage. These include:

(1) reducing the available light by blanketing the seagrasses with an excessive load of epiphytes. This is caused by an increased nutrient load in the water column. Nutrients may originate from a variety of sources, including agricultural fertiliser run-off, industrial and domestic effluent, and all sources of sewage such as treatment plant outfalls, septic systems leaching into the water table, aquaculture and boats at anchorage. Borum (1985) demonstrated a 50- to 100-fold summer increase in epiphyte biomass on *Zostera marina* along a nutrient gradient. This nutrient originated principally from domestic and industrial effluent;

(2) reducing the available light by increased turbidity in the water. This is caused by an increase in solids suspended in the water column. Sources of solids include topsoil from agricultural activities and forestry, erosion due to coastal engineering and dredging (Taylor & Saloman 1968). Sedimentary particles are also progressively released as seagrass beds decline. Phytoplankton blooms resulting from eutrophic conditions may have a similar effect on light attenuation;

(3) mechanical damage due to dredging, and boat anchorages (Lukatelich *et al.* 1987). Digging mud worms for bait also falls into this category (Luck 1990); and

(4) toxic effluents.

Other apparently natural mechanisms may be indirectly attributable to ecosystem damage caused by other human activities. One example is the activity of burrowing crustaceans causing dieback by covering seagrass leaves with silt. Suchanek (1983) researched the activity of species of ghost shrimp (*Calianassa* spp.) in seagrass meadows whose considerable population increase may have been due to the reduction of predators by over-fishing. It was found that up to 2.6 $kg/m^2/day$ of sediment was ejected out of small volcano-like mounds, and that seagrass productivity and density in the area was negatively correlated to the density of *Calianassa* mounds.

1.4.3 Natural variance in seagrass distribution

There are cases of small and large changes in seagrass distribution that have not been directly attributable to human activity. One example is the 'wasting disease' that almost brought to extinction the entire population of the species *Zostera marina* in the North Atlantic (den Hartog 1983). Similarly, Orth and Moore (1983) using aerial photography of the Rappahannock River, Virginia, U.S.A., demonstrated significant regrowth of *Z. marina* and *Ruppia maritima* L. between 1937 and 1968 after die-back at the time of the 'wasting disease'. This was again followed with a complete decline by the late 1970's. The cause of the 'wasting disease' is still the subject of speculation, but may have been the result of a cyclical combination of factors including a rise in sea temperatures (Larkum & den Hartog 1989). Kerr and Strother (1990) studied *Zostera muelleri* over an 18 month period in Victoria and found seven-fold and forty-fold changes in above-ground biomass at two sites between summer and winter.

In Tasmania, cyclical changes in biomass have been described in some areas by local observers, and these can be confirmed with archival aerial photography. Examples include the recent rapid proliferation of *Heterozostera tasmanica* in Cloudy Lagoon, and mild cycles in the density of the same species in Blackman Bay and Southport Lagoon.

It is likely therefore that there is an inherent cyclical variation in the biomass and area covered by seagrass populations (King & Hodgson 1986), which only long-term studies can reveal. More rapid biomass losses may be caused by damage from severe storms.

The examples discussed above suggest that there are natural patterns of change in seagrass biomass and distribution which must be distinguished from those attributable to human activity. In reality, because of the human pressures on the coastal zone in most places that seagrasses occur, the presence of pollutants in even the most remote parts of the ocean, and the large-scale climatic changes our species is causing, it is not possible to say more than that natural cycles exist. Their rhythm and origins are, in probability, corrupted. However, long term studies can reveal their shadows amongst the trends related to any ongoing human impact.

1.5 Tasmanian seagrasses

The distribution of seagrasses around Tasmania is the major focus of this study, and it is useful to place the biogeography of the State's seagrasses in the wider Australasian picture.

1.5.1 The Tasmanian seagrass flora in a regional context

Australia has a rich seagrass flora, with eleven genera represented. It has more species than any other continent, eighteen of them endemic, and sixteen of these found in temperate waters. It is probable that the seagrass species of Australia represent a relict flora that has avoided the extinctions suffered elsewhere on the planet. Much of this diversity, however, is found in tropical waters and on the west coast, with a tendency for the number of species to reduce from north to south down the eastern seaboard, and from west to east along the southern coast. Tasmania thus has the lowest number of species of any part of Australia.

The theoretical and research findings relating to Australian seagrass biogeography have been summarised by Larkum and den Hartog (1989). These researchers divide Australian temperate seagrasses into five groups based on their geographical distribution. Tasmanian seagrasses fall into three of these groups:

(1) those present in all temperate regions including the east coast of Australia (Two species, *Heterozostera tasmanica*, and *Posidonia australis*. Both are found in Tasmania);

(2) those restricted to the west coast and the Great Australian Bight (and in some cases Victoria) (Eleven species represented only by *Amphibolis antarctica* in Tasmania); and

(3) those with very restricted distribution on the southern coast of Australia, mainly in Victoria and Tasmania but sometimes extending to South Australia and into N.S.W. (Two species, *Halophila australis* Doty & Stone and *Zostera muelleri*. Both are found in Tasmania).

Of Tasmania's five species, three represent genera that are endemic to the temperate waters of Australia. These genera are *Posidonia, Amphibolis* and *Heterozostera*, and of these the species *Posidonia australis* and *Amphibolis antarctica* occur in Tasmania at the southerly limit of their distribution. Both appear to be confined to the north coast and Bass Strait islands with only scattered patches of *A. antarctica* at a handful of sites on the Tasmanian east coast (Edgar 1981, 1984b). Of the three genera, only *Posidonia* has a northern hemisphere species, *P. oceania* found in the Mediterranean. *H. tasmanica* has been recorded in several locations on the coast of Chile (Phillips *et al.* 1983; Gonzalez & Edding 1990).

It is likely that these genera had a wider distribution around the coasts of Gondwana in the Palaeocene era, and only avoided extinction in the relative stability of the Australian coastal environment since that time. Their confinement to the southern coasts of Australia has probably resulted from the slow northward drift of the continent into warmer tropical waters since the break-up of Gondwana.

The other two genera found in Tasmania, *Halophila* and *Zostera* have species in warmer, more northerly Australian regions and a wide global distribution (Larkum and den Hartog 1989).

1.5.2 Tasmanian seagrass species

This study has looked at the distribution of the five species of temperate seagrass found in Tasmania. These are:

Amphibolis antarctica (Labill.) Sonder et Aschers.
Halophila australis Doty & Stone
Heterozostera tasmanica (Marten ex Aschers.)
Posidonia australis Hook. f.
Zostera muelleri Irmisch & Aschers.

The classification adopted by Robertson (1984) places them thus:

Division **Magnoliophyta** Cronquist, Takhtajan & Zimmerman (Angiospermae)

Class **Liliopsida** Cronquist, Takhtajan & Zimmerman (Monoctyledonae)

Subclass Alismatidae Takhtajan (Helobiae of Fluviales)

Of the five orders in the Alismatidae, two are represented in southern Australia, the Hydrocharitales (*Halophila* spp.) and the Potamogetonales (*Amphibolis* spp., *Heterozostera* sp., *Posidonia* spp. & *Zostera* spp.)

Species from the genera *Ruppia* and *Lepilaena* (also included in the order Potamogetonales) have not been considered in detail in this study, an exclusion made principally to contain the scope of the project to coastal waters. These species can extend from brackish into fresh water, including inland waters such as swamps and lakes (Robertson 1984; Hughes & Davis 1989). The two genera *Ruppia* and *Lepilaena* are not included as seagrasses in Larkum and den Hartog (1989), but are described by Robertson (1984) as marine annuals, *L. marina* being found in the eulittoral zone in association with *Zostera muelleri*, and occasionally subtidally.

Ruppia maritima, *R. polycarpa* and *R. megacarpa* are described by Hughes and Davis (1989) as occurring in a number of estuaries around the state. In the present project, *Ruppia* spp. were recorded when found growing in association with seagrass species.

No other seagrass species has been identified in Tasmania prior to this study, although Kuo and McComb (1989) include Tasmania in the range of *Halophila ovalis* (R. Br.) Hook, and this is the *Halophila* species described by Edgar (1984b) as occuring in the D'Entrecasteaux Channel. It appears that the species may in fact be *H. australis.* No other reference could be found for this species' presence. It remains possible that *H. ovalis* and perhaps other species of *Posidonia* might occur in the extensive seagrass communities of the Bass Strait and islands.

The most comprehensive account of Tasmanian seagrass distribution to date was given by Hughes and Davies (1989). This work represents the compilation of a number of references to seagrasses in the State, including herbarium records and limited field work on the part of the author (J. Hughes, pers. comm. 1992). Last (1983), and various studies by Edgar (1981, 1984a, 1984b) were referred to by Hughes in addition to personal accounts. Distribution maps were produced for each of the species (see below). Apart from the works of these three researchers, references to seagrasses in Tasmania are rare. Any research references and oral accounts are included in my results (Chapters 5 and 6) in conjunction with the relevant coastal area.

Some major attributes of the five species, all rhizomatous perennials, are given below:

1.5.2.1 *Amphibolis antarctica* (Labill.) Sonder et Aschers.

This species is found growing in sand or mud below the high tide level and rarely deeper than 12 m (Shepherd & Robertson 1989). The rhizomes branch frequently and send up numerous wiry, erect, much branched stems from 0.2 m to 1.5 m tall. The branch ends support tufts of 8 to 10 leaves, with the annular scars of the old leaves clearly visible on the branches and stems. The leaves are up to 50 mm long and are usually twisted through 180 degrees along their length (see Figure 1.1).

Amphibolis antarctica can form extensive dense stands, and is able to tolerate turbulent and moving waters. In common with *Heterozostera tasmanica* and *Halophila australis*, the species is considered a pioneer following a perturbation (Shepherd & Robertson 1989).

The tall, woody stems of *A. antarctica* can support a large load of macroalgal epiphytes. This makes it more vulnerable to shading than species with shorter lived leaf blades (Shepherd *et al.* 1989). Epiphytes show a clear pattern of distribution on the stems and leaves of this species, with bryozoans and hydroids found more commonly attached to the lower part of the stem, and macroalgae

Figure 1.1

Amphibolis antarctica, appearance and distribution (Hughes & Davis 1989)

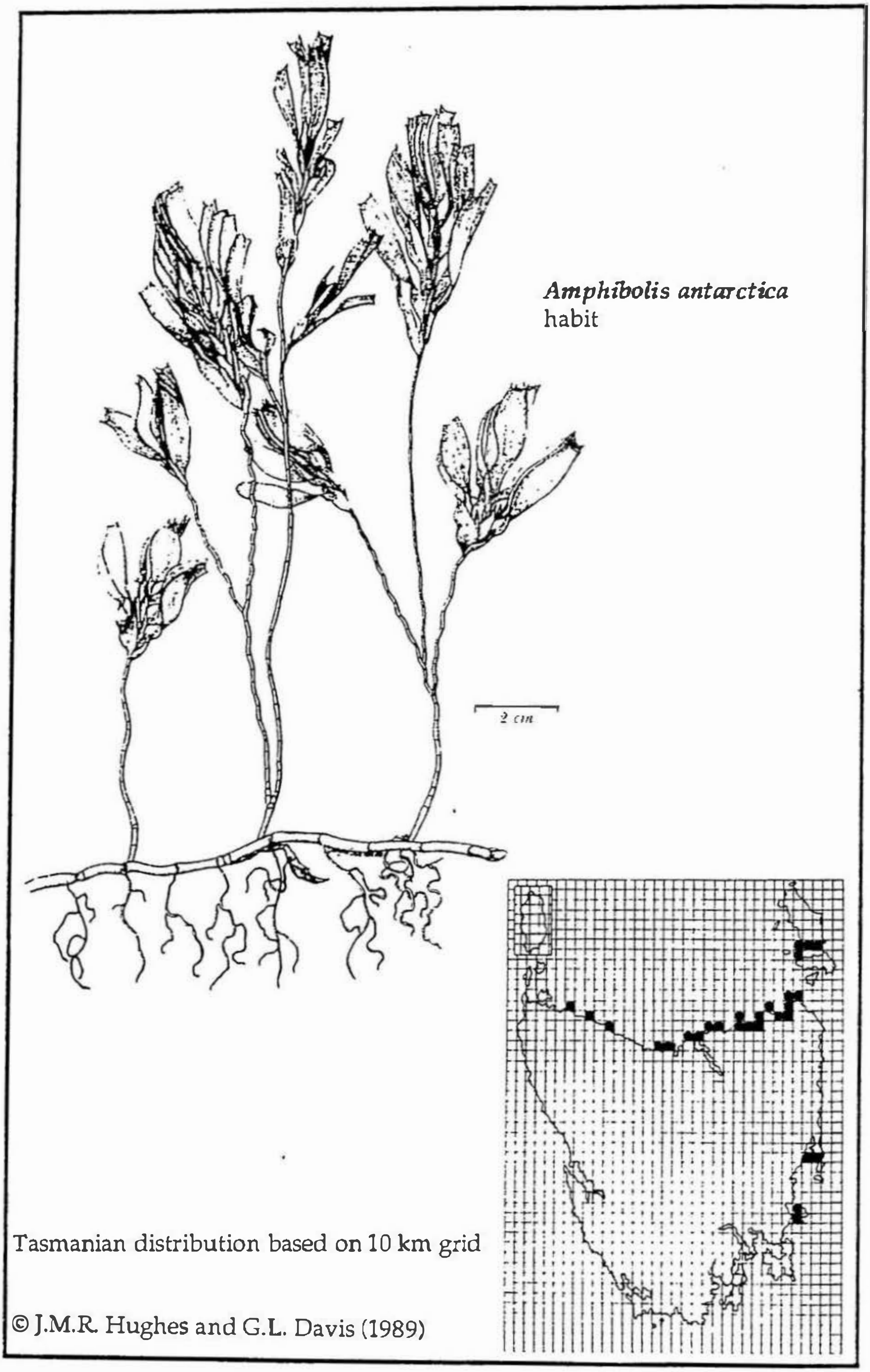
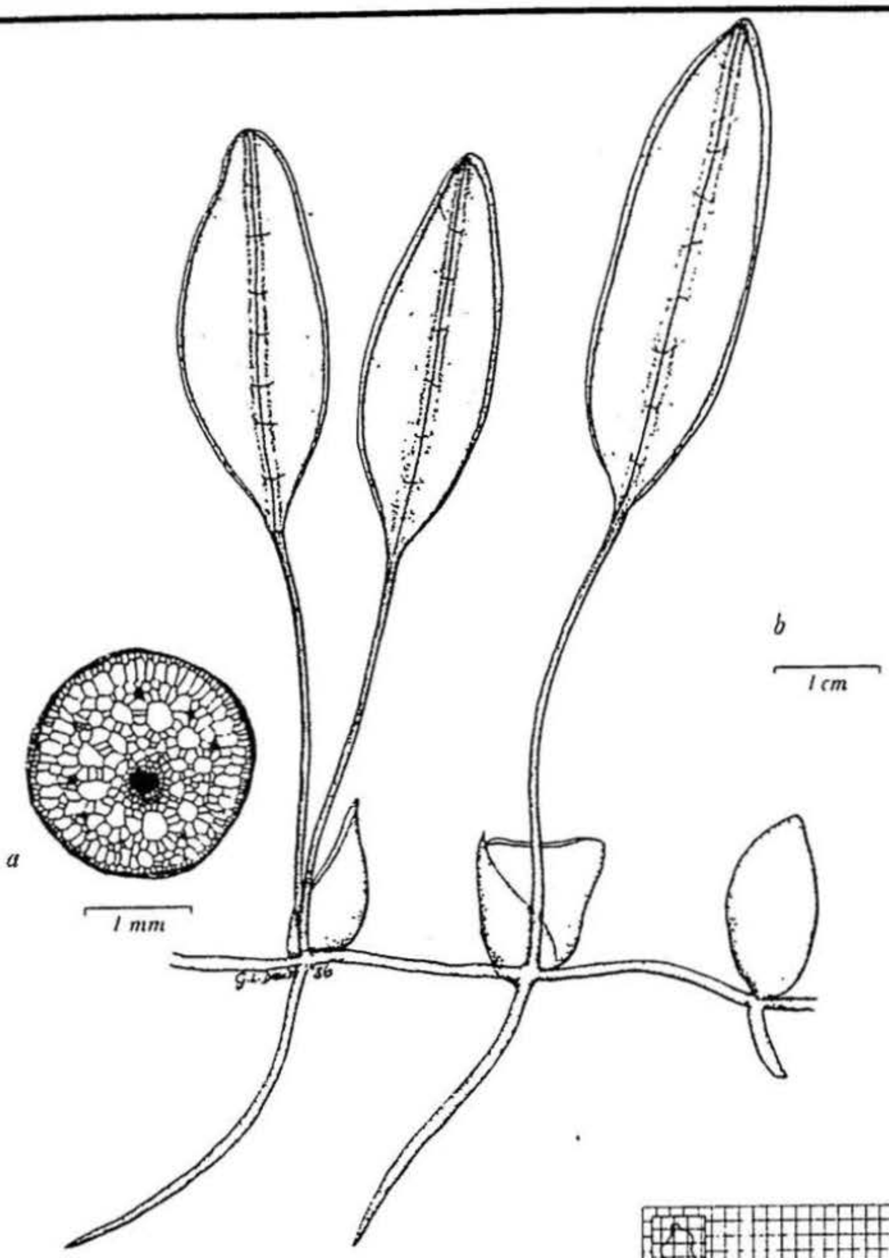
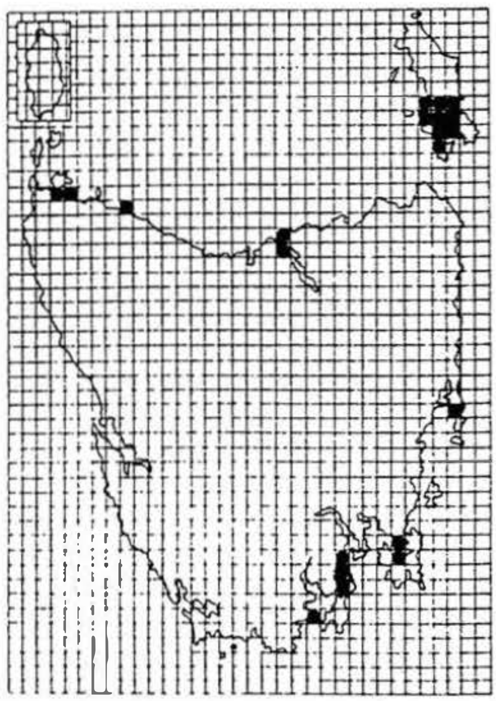


Figure 1.2

Halophila australis, appearance and distribution (Hughes & Davis 1989)



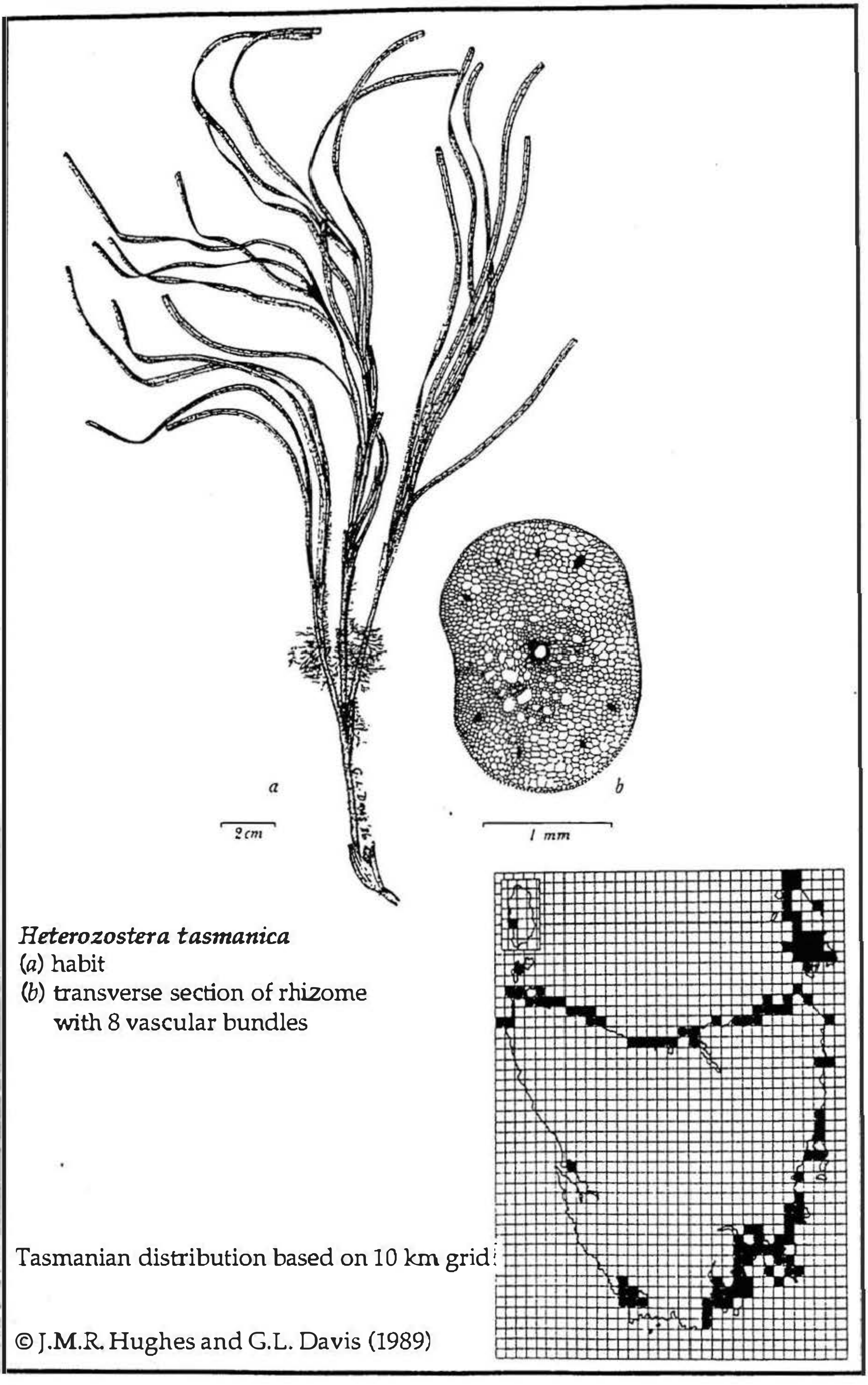
Halophila australis
(*a*) transverse section of rhizome
(*b*) habit



Tasmanian distribution based on 10 km grid

Figure 1.3

Heterozostera tasmanica, appearance and distribution (Hughes & Davis 1989)



Heterozostera tasmanica
(*a*) habit
(*b*) transverse section of rhizome
with 8 vascular bundles

Tasmanian distribution based on 10 km grid

Figure 1.4

Posidonia australis, appearance and distribution (Hughes & Davis 1989)

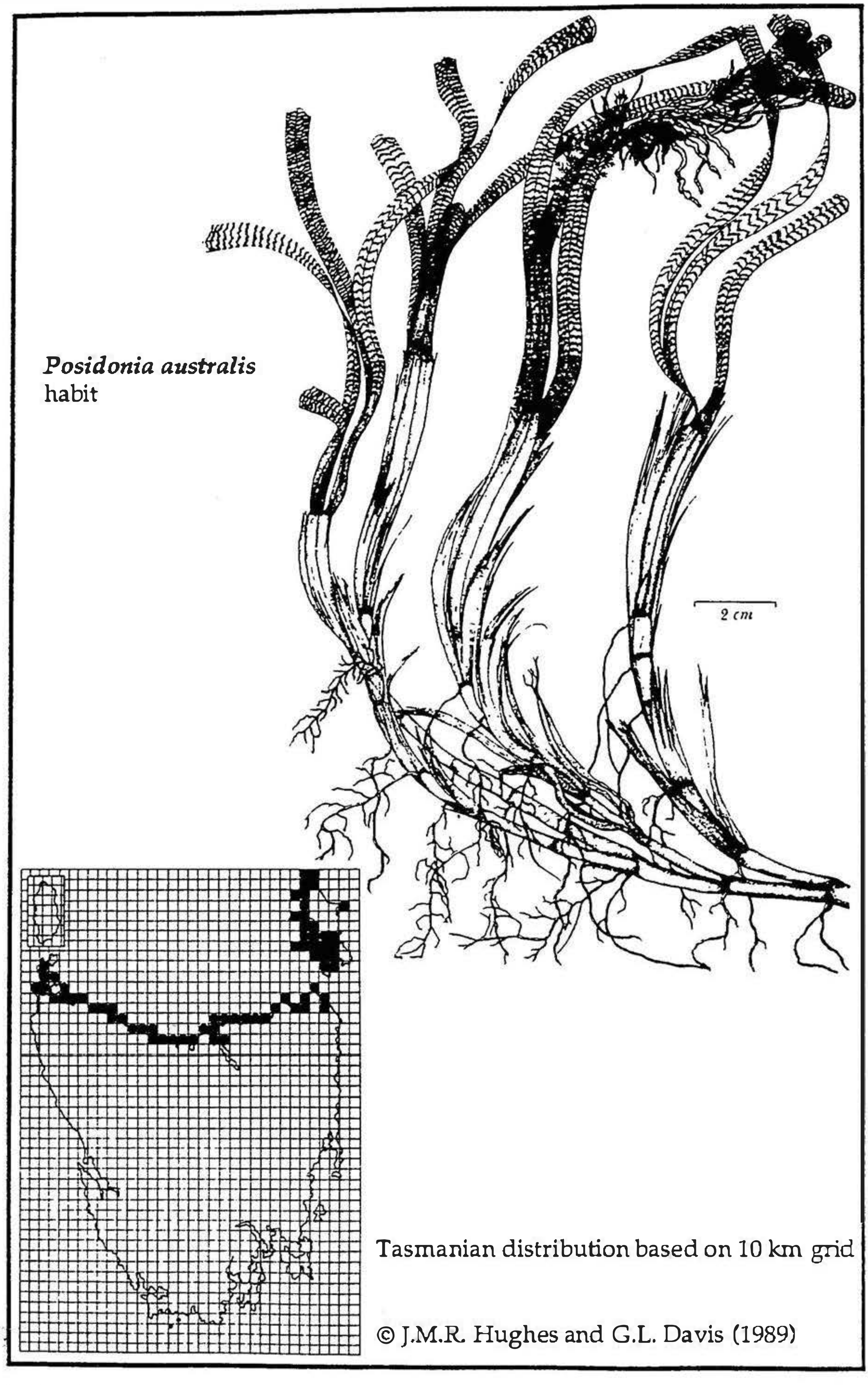
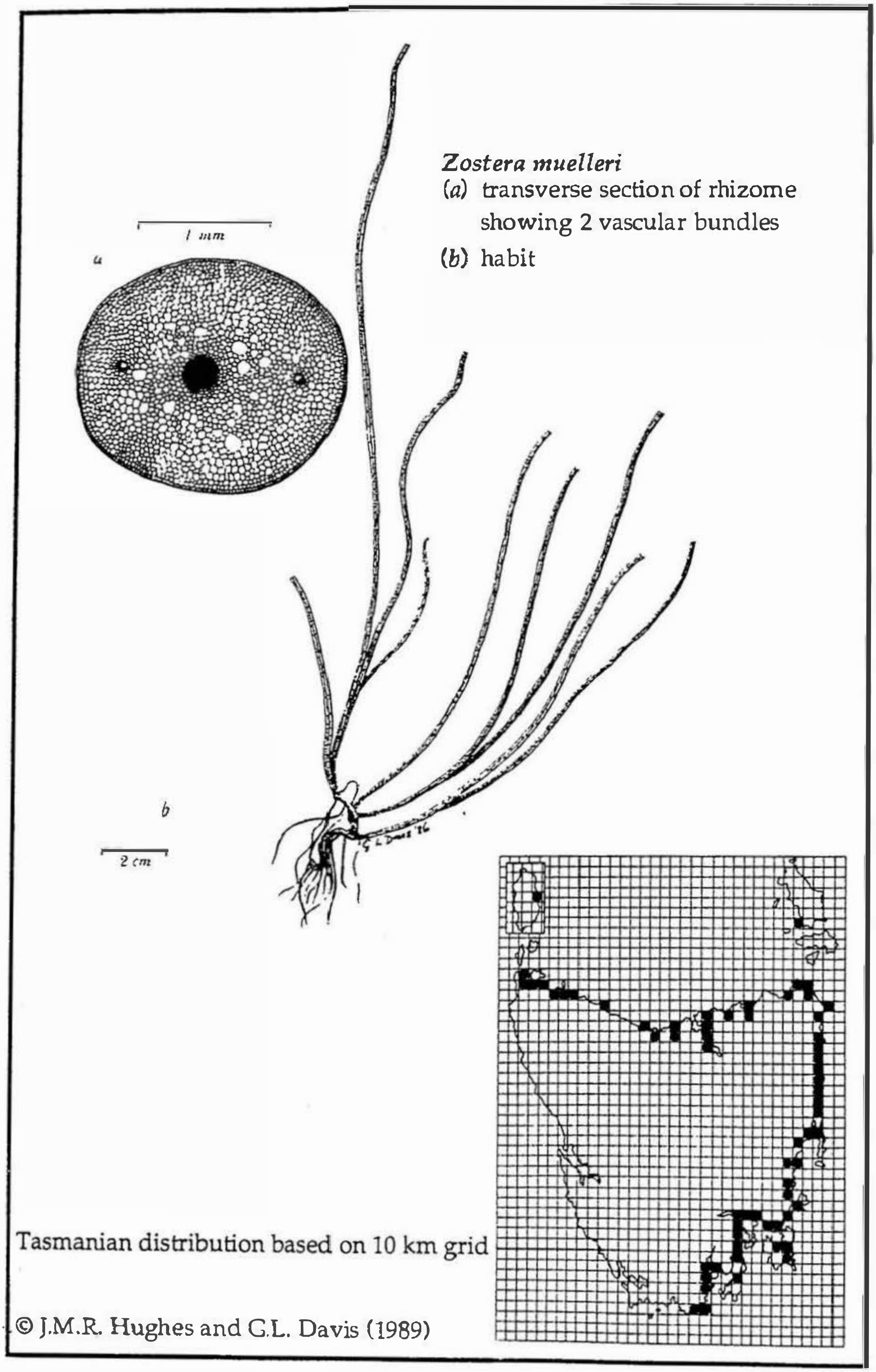


Figure 1.5

Zostera muelleri, appearance and distribution (Hughes & Davis 1989)



dominating the stem apex. The apex can support some 80% of the biomass of macroalgal epiphytes (Borowitzka & Lethbridge 1989). *A. antarctica* is thus very susceptible to smothering by epiphytic algal growth due to nutrient enrichment.

1.5.2.2 *Halophila australis* Doty & Stone

The species is easily recognised by its delicate light-green translucent leaves (see Figure 1.2). *H. australis* prefers calm sheltered waters, and tolerates a wide range of substrata, including unstable sediments (Hughes & Davis 1989). It is often found growing in conjunction with other seagrasses, and to a depth of 10 m, though occasionally over 15 m (see Chapter 5).

Species of the genus *Halophila* could be classed as opportunist plants, and regularly produce vegetative structures and flower frequently (Larkum & den Hartog 1989). They are often the first recolonisers of suitable habitat after a perturbation.

1.5.2.3 *Heterozostera tasmanica* (Marten ex Aschers.)

The vegetative shoots may reach over 50 cm high, and with age become brown and wiry. This wiriness does not occur in *Zostera muelleri*, and is one way to separate the species. The leaves are bright green and grass-like, growing in a tuft from the shoot. They are linear, usually 2-3 mm wide and up to 35 cm long (see Figure 1.3).

H. tasmanica is most common in sheltered marine habitats including offshore areas where it may occur beyond 15 m depth. It forms large stands in shallow bays, and it also penetrates into brackish environments. The species favours sandy and muddy substrata below low tide, although it can tolerate limited exposure (Hughes & Davis 1989).

1.5.2.4 *Posidonia australis* Hook. f.

Of its genus, only *Posidonia australis* has been recorded in Tasmanian waters. The species is limited to Bass Strait including the Furneaux and Kent groups of Islands, and the lower reaches of the Tamar Estuary. It has a broad flat leaf (10-15 mm), growing up to 45 cm in length (see Figure 1.4). It grows subtidally in the clear water of sheltered estuaries and bays to a depth of 10 m, favouring a sandy substratum (Hughes & Davis 1989), and may cover many square kilometres.

Posidonia leaf blades support lower standing crops, and of much smaller algal and other epiphytic loads than *Amphibolis antarctica* (Shepherd *et al.* 1989). West and Larkum (1979) found that the rate of leaf turnover in summer was around 2.5 times that measured in the winter months in eastern Australian waters. They found the mean life-span of *P. australis* leaves to be between 91 and 125 days, whereas Silberstein et al. (1986) measured a mean leaf life-span of 65 to 75 days in Cockburn Sound, W.A.

1.5.2.5 *Zostera muelleri* Irmisch & Aschers

This species is dominant in the lower reaches of open systems and sheltered intertidal mud flats. It colonises shallower water than *H. tasmanica* and is often exposed at low tide (see Figure 1.5). Extensive beds grow on sandy or muddy substrata (Hughes & Davis 1989). Its leaf blade is similar in width to *H. tasmanica*, and cannot be distinguished from that species in detritus. A microscopic examination of the arrangement of vascular bundles in a rhizome cross-section is a reliable method to differentiate between *Z.muelleri* and *H. tasmanica.*

Robertson (1984) describes two forms of the species *Zostera muelleri* which have the same distribution but are found in different ecological niches. *Z. muelleri* estuarine form has a leaf width and length equivalent to *H. tasmanica* with which it can readily be confused, whereas *Z. muelleri sensu stricto* has much narrower and shorter leaves. Both these forms were found in this study.

1.6 This Project

The impetus for this study came from the growing concern amongst sections of the Tasmanian government and public that planning and management relating to coastal development, fisheries and marine conservation was being limited by the lack of knowledge of seagrass communities. It was feared that seagrasses in Tasmania, like those elsewhere, were under threat, or had declined in some areas. This was supported by anecdotal evidence of losses in some parts of the State.

The principal objective of the project has been to develop an overall picture of the present location, extent and species composition of seagrass communities in Tasmania, and collate data of their past distribution from all sources to indicate any changes that have occurred. In attempting to achieve this objective, a central issue has been to explore the feasibility of mapping seagrass beds from details revealed in available aerial photographs of the Tasmanian coast.

1.6.1 Aims

(1) to add to current knowledge of the distribution of the five seagrass species occuring in Tasmania: *Amphibolis antarctica, Halophila australis, Heterozostera tasmanica, Posidonia australis* and *Zostera muelleri;*

(2) to relate species distribution to measured physical parameters such as the degree of exposure to wave action, depth, substratum and coastal geomorphology;

(3) to determine changes in the distribution and extent of seagrasses in Tasmania since *circa* 1950 to the present day;

(4) to relate changes in the area of seagrass to the incidence of algal epiphyte growth on seagrasses;

(5) to evaluate the usefulness of aerial photography for the remote sensing of seagrass communities; and

(6) to identify areas containing representative communities of the five species of seagrass in Tasmania suitable for inclusion in future marine reserves.

1.6.2 Hypotheses

The thesis sets out to test the following hypotheses:

(1) that there have been large scale quantitative reductions in the occurrence of seagrasses in Tasmania since *circa* 1950; and

(2) that where such reductions have occurred, they correlate with the levels of algal epiphytes observed on seagrass beds in the present.

1.6.3 Scope and limitations

The goal of the sampling program was to investigate all areas of the Tasmanian coastline with suitable seagrass habitat. Due to problems with weather and other unforeseen variables, and the limitations of time, some areas were not visited.

The sampling program was carried out in the summer and autumn months of 1992, with some minor additional sampling in spring 1992 and summer 1993. Sampling was restricted to using a periscope and dredge, with very occasional snorkelling. Cost factors proscribed the use of SCUBA.

Remotely sensed data was limited to that available from the Tasmanian Department of Environment and Planning, and the University of Tasmania. For aerial photography, no special flights were affordable, and as a result the photographs used varied considerably in scale and quality. Landsat imagery was limited to scans available from the Central Science Laboratory at the University of Tasmania.

Some cyclic changes in seagrass cover were not researched in this project. These include annual seasonal variations and longer term cyclical changes in seagrass extent and coverage, and seasonal and long term changes in epiphytes, water turbidity and sedimentation.

The project needs to be considered in light of the size of the task undertaken, and the limited resources and time available. Within those constraints it presents as detailed as possible an overview of Tasmanian seagrass communities.

1.6.4 Report structure

This thesis has first placed Tasmanian seagrass species in the context of the ecological significance and sensitivity of seagrasses generally. Before presenting the results and conclusions, the marine coastal environment in Tasmania is considered and a classification of coastal habitats adopted; the literature concerning seagrass mapping and boundary definition is discussed and a suitable approach derived; and, a detailed description of the research methodology is given.

The results are divided into two chapters. In Chapter 5, the distribution of each seagrass species is described, based on sample data, including a profile of preferred habitats in the Tasmanian context. The extent of seagrass communities in a subset of sample areas is presented in map form. These represent a range of coastal types from different regions of the State. The distribution is compared with that known before this study. In Chapter 6, changes in seagrass distribution from a smaller group of sample areas are mapped and calculated to test the first hypothesis. The rate of decline in these areas is correlated with the occurence of algal epiphytes in samples to test the second hypothesis (Section 1.6.2). Other impacts on seagrass communities are also recorded and discussed.

Finally, the results are considered in the context of the literature on seagrass distribution and causes of decline. The methodology is critically reviewed, including the use of aerial photographs. Further direction for research are identified, and, from the information on seagrass species distribution, representative areas are nominated as sites for possible protection as marine protected areas or wetland reserves.

A secondary outcome of the study is a GIS database containing information on a majority subset of seagrass communities in Tasmania. This data indicates the distribution of the seagrass species found in the areas sampled in 1992 and 1993, and, in a number of areas of the coast, holds outlines of seagrass beds that describe the extent of communities in the past and present. This information can form a reference for more detailed studies on seagrasses in Tasmania, and can be combined with other data to assist research, planning and management in Tasmania's coastal zone and marine environment.

Plate 1:
Zostera muelleri habitat in different parts of Tasmania

Melaleuca Inlet, south west Tasmania. *Zostera muelleri* occurs in beds along the inlet and in Melaleuca Lagoon

East Inlet, near Stanley, north west Tasmania. *Zostera muelleri* beds exposed at low tide

Plate 2:

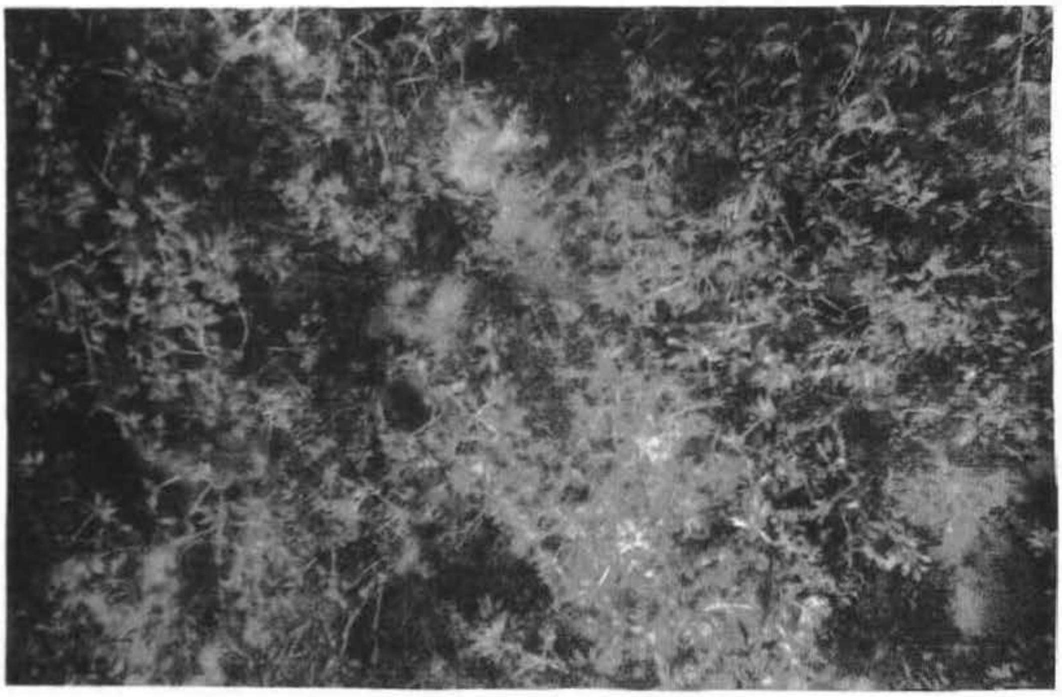
Posidonia australis and *Amphibolis antarctica* beds in north east Tasmania

The boundary between *Amphibolis antarctica* and *Posidonia australis* at 3 m off Little Mussel Roe beach, north east Tasmania

The shallow boundary of the seagrass bed (seen above) off Little Mussel Roe beach, north east Tasmania

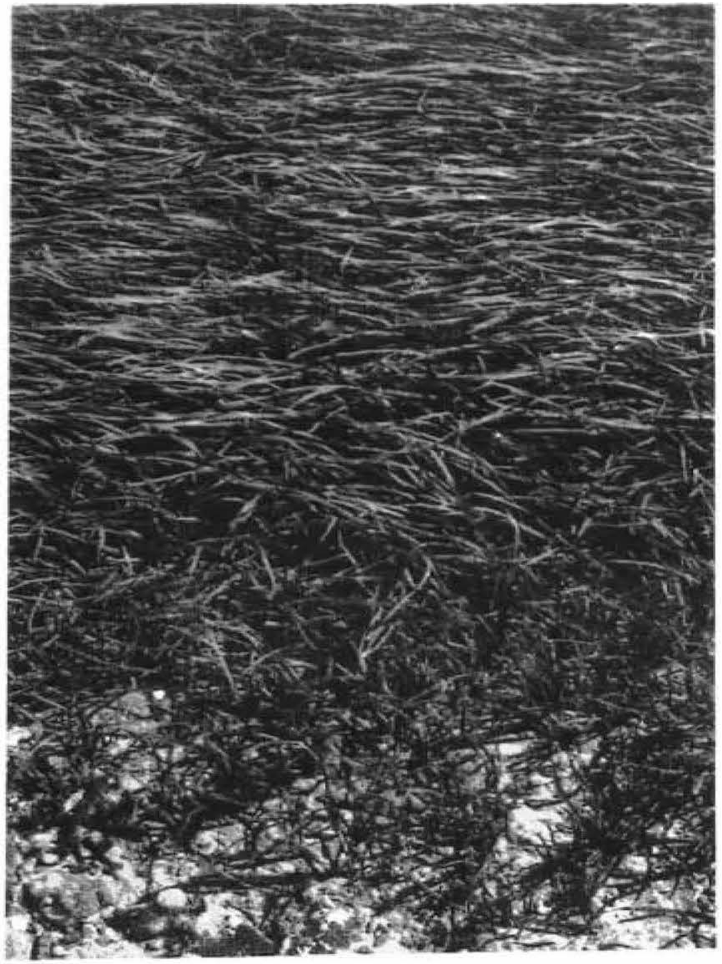
Plate 3:
Amphibolis antarctica and *Heterozostera tasmanica* appearance

Heterozostera tasmanica in Cloudy Lagoon, Bruny Island, south east Tasmania, showing some algal epiphyte presence



Amphibolis antarctica in shallow water off Maria Island, east coast of Tasmania

Plate 4: ***Posidonia australis***, *Heterozostera tasmanica* and *Zostera muelleri* appearance



Posidonia australis with a fringe of *Heterozostera tasmanica* in shallow pools off Greens Beach, north coast of Tasmania

Zostera muelleri on intertidal flats at West Inlet, near Stanley, north west Tasmania

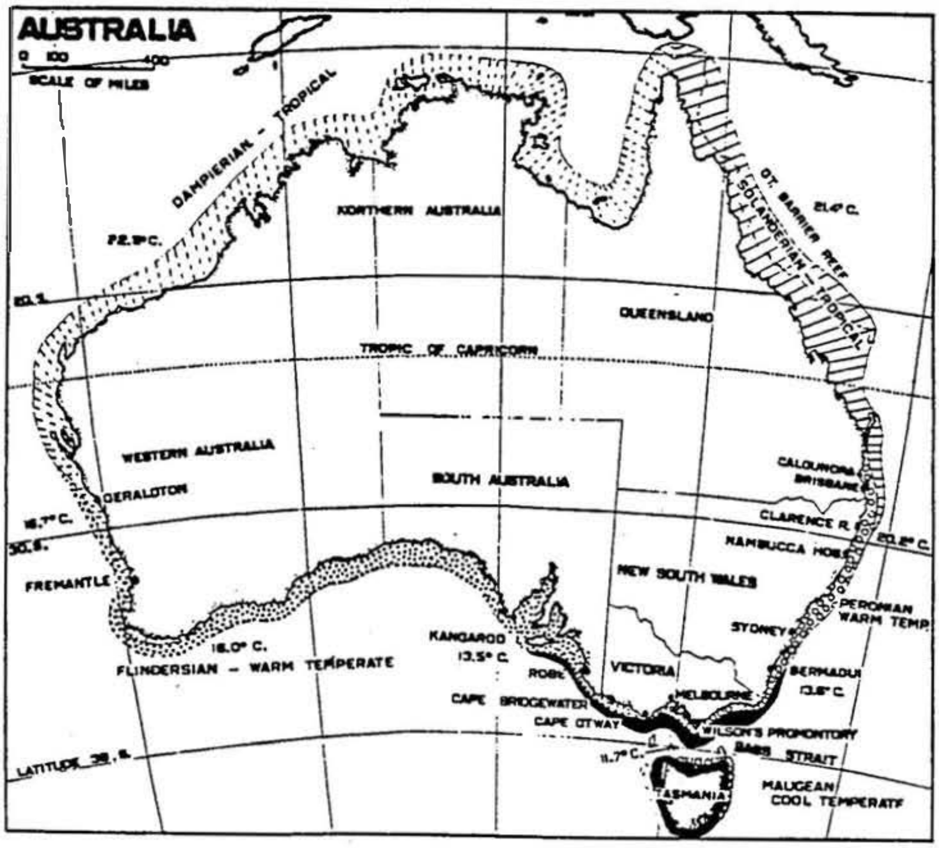
Chapter 2
THE TASMANIAN COAST & SEAGRASS HABITAT CLASSIFICATION

This chapter considers the nature of the coast of Tasmania in the context of seagrass habitat. The coastal climate of the region is reviewed, and there is a brief consideration of selected water quality parameters that may influence seagrass distribution. The factors limiting seagrass habitat are also considered. Finally, some approaches to the classification of coastal habitats are reviewed, and the system adopted in this study is described.

2.1 Tasmanian coastal climate

The coastal climate of Tasmania can be described as temperate maritime (Last 1983). There are significant differences however between the climates of different regions of the State. These have an impact on marine conditions, and thus influence the availability of seagrass habitat. The variations are due to the nature of the prevailing winds, offshore currents, rainfall in adjacent catchments, tidal patterns, water and air temperatures.

Figure 2.1:
Biogeographical provinces of the Australian coastline (Bennett & Pope 1953).



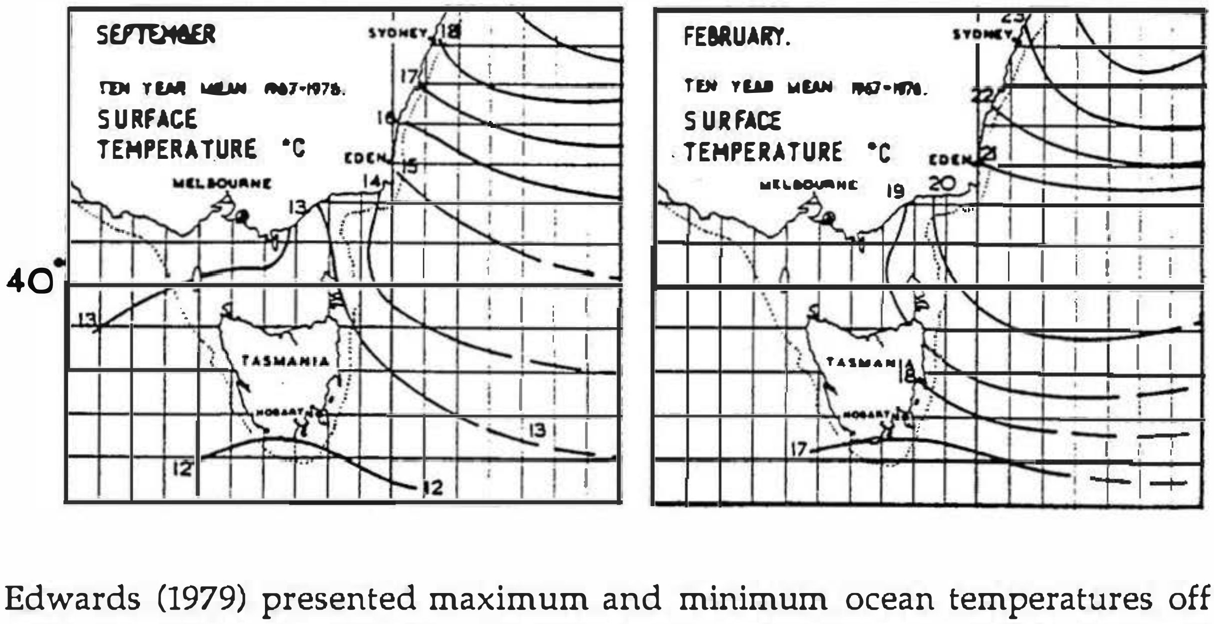
The Tasmanian marine flora and fauna have been placed in the Maugean sub-province (Womersley 1981). This name was first coined by Iredale and May (1916) based on the distribution of various species of chiton. They described a zone encompassing South Australia, Victoria and Tasmania (see Figure 2.1). There has been some debate around the biogeographic integrity of such a region (see Edgar 1981). For example, Bennett and Pope (1960) regarded Victoria and Tasmania to be a separate cool-temparate province. The accepted criterion is that the coastal region in question possesses a relatively homogeneous and distinct flora and flora. Edgar (1984b) acknowledged the existance of a separate cool temperate province (the Maugean) centred on the eastern, southern and western coasts of Tasmania, but that the northern and north-eastern coasts are also influenced by the Flindersian and Peronian provinces respectively.

2.1.1 Water Temperature

Water temperature is a key factor affecting the biogeography and ecology of inshore intertidal and subtidal areas (Womersley 1981). Whilst offshore sea temperatures change gradually over the year and follow annual patterns fairly closely, inshore and estuarine water temperatures are under a number of influences and show wider fluctuations.

Figure 2.2:

Tasmanian mean summer and winter ocean temperatures (Edwards 1979)



Edwards (1979) presented maximum and minimum ocean temperatures off Tasmania averaged over ten years (see Figure 2.2). These show differences of over a degree Celsius between the North and South of the state. There are, however, marginal annual variations, and Harris *et al* (1987) indicated a slight warming trend and a cyclic fluctuation over a 10-15 year period off Maria

Island on the East Coast.

In summer, ocean temperatures are under the influence of a migration of the East Australian Current, which extends subtropical water occasionally as far as the south east tip of the State. In winter, there is an incursion of subantarctic water as far as the north east corner of the State (Harris *et al.* 1987). Mean summer water temperatures (March) in the south approach 18°C and in the north 19°C. In winter, southern mean temperatures are 12°C, and in the north 13°C (Edwards 1979).

Inshore water bodies experience a broader range of temperatures. For example, Last (1983) measured summer maximum surface temperatures of 30.4°C and winter minima of around 0°C in some small brackish lagoons. Thompson (1959) recorded minimum temperatures of 1.5°C and a maximum of 30°C in Port Sorell, and Mollison (1963) describes a range of 3°C to 26°C in Pittwater. Temperature fluctuations in most larger open coastal water bodies would be less extreme due to the moderating effect of oceanic water.

2.1.2 Wind regimes

The prevailing wind direction for Tasmania is westerly, although the dominant anti-cyclonic circulations in summer, and cyclonic circulations in winter produce periods of northeasterly and southeasterly winds. These can blow for a number of days and generate large swells on the east and north coasts. The west coast experiences almost continuous swells from the predominantly north-westerly winds to the north, and south-westerly winds in the south. These winds are strongest in winter and spring. Onshore sea breezes may develop from late spring through the summer in all coastal areas, at times being quite strong and producing rough seas, especially in the south east and along the Bass Strait coastline.

2.1.3 Air temperatures

Air temperatures for the State range from mean summer maxima of 17°C to 23°C, and mean winter minima of 2.5°C to 7°C. These contribute to fluctuations in the water temperatures of shallow areas and exposed intertidal flats that are greater than the adjacent coastal water.

2.1.4 Tides

Tidal ranges vary from maxima of around 0.8 m in the southern Tasmanian region to as much as 3.3 m in parts of the Bass Strait. Locally, tides may vary significantly from this, subject to the occurence of onshore winds and the barometric pressure.

2.2 Tasmanian coastal water quality

In many areas of the State, the condition of coastal water can be considered relatively pristine in terms of clarity and salinity, and close to its oceanic origins. In some regions, however, it is significantly modified by inputs of freshwater and other materials from both natural and and human sources.

2.2.1 Turbidity and pollution

Many of the State's estuaries have extensive urban and industrial development and associated pollution problems. The Derwent River catchment, for example, received over 11 billion litres of domestic effluent and over 67 billion litres of industrial effluent per year in the 1970s (Tasmanian Department of Environment 1977). Later annual reports from the Tasmanian Department of Environment indicate that most pollutants have continued at these levels.

On the North West Coast, a polluted zone extends from Table Cape in the West to Point Sorell in the East (Tasmanian Department of Environment 1989b). Along this length of coast a number of sources of pollution add large quantities of chemical contaminants and nutrients to inshore waters, and in some cases, such as the Tioxide plant at Heybridge, significantly increase turbidity (Ritz *et al.* 1985).

There are many materials of both natural and human origin that can increase turbidity. Natural causes include the resuspension of fine particles from the floor of the water body by wave turbulence, and the brown staining due to tannins derived from certain organic soil types, such as peat. All western, southern and southeastern rivers and streams from the Detention River in the North West to the Huon River in the South East are deeply stained. This includes Macquarie Harbour and the Bathurst Harbour complex. In addition, rivers east of the Tamar as far as Ansons River are deeply stained where they drain the North East coastal plain (Mollison 1963).

Human causes of turbidity include urban and agricultural runoff, mine tailings, dredging and erosion from forestry operations. These all contribute suspended solids and in some cases nutrients and other contaminants to the water column. Forestry operations can have a marked detrimental effect on water quality in the period immediately after felling, and may cause a sharp increases in the level of suspended solids (Singline *et al.* 1982). The advent of cable logging on steep slopes in parts of the State is therefore of concern. Its impact on sedimentation and turbidity in estuarine and coastal waters requires investigation.

2.2.2 Salinity

In the Tasmanian region the salinity of offshore surface water varies between 35.1‰ and 35.5‰ (Edwards 1979). However, inshore and estuarine water may vary considerably from these levels. Large influxes of fresh water from adjacent catchments will lower salinity, and evaporation will raise salinity.

Mollison (1963) described the extremely complex vertical and longitudinal variations in salinity in Tasmanian estuaries and lagoons. Some lagoons, for example, may experience a complete change from fresh to marine salinities with each tidal cycle. Stratification of water with differing salinities is common, with a tidal wedge of dense marine water penetrating many estuaries and lagoons beneath fresh water of catchment origin. Wind may cause intermixing of these layers and homogenise the salinity, but this will depend on its direction, velocity and frequency.

Additionally, coastal water itself may be diluted for some distance by the large volumes of limnetic water flowing from some of the States rivers. This is particularly true on the West Coast, where the annual rainfall average is 3 700 mm compared to 500 mm on the East Coast (Tasmanian Bureau of Meteorology, pers. comm.).

Table 2.1:
Classification of brackish and marine waters based on salinity
(adapted from Last 1983)

Zone	Salinity Range ‰
Limnetic (freshwater)	< 0.5 ‰
Mixohaline (brackish)	0.5-30 ‰
Euhaline (marine)	30-36 ‰
Hyperhaline	> 36 ‰

2.3 Seagrass habitat description and classification

2.3.1 Seagrass habitat

Seagrasses are found in a variety of intertidal and subtidal soft-bottomed habitats. Their preference is generally for shallow sheltered areas with low wave energy and optimal light levels. A number of factors affect seagrass productivity, and restrict the available habitat. These include light, water temperature, water energy, salinity and sediment characteristics.

(a) Light

The light available to seagrasses varies according to latitude, season, depth and absorption by suspended or dissolved matter in the water column. Perfectly clear water will ultimately attenuate light with increased depth to the point that it limits seagrass photosynthesis. In general, most seagrasses are found in shallow water of less than 10 m, but some species can be found as deep as 30 m in exceptionally clear water. An example is the occurrence of *Posidonia angustifolia* and *Posidonia coriacea* at 25-30 m depth off the western coast of the Eyre Peninsula in South Australia (Shepherd & Robertson 1989). *Halophila australis* has been reported growing at depths of up to 17 m in the Furneaux Group (J. Mason 1992, pers comm.).

As indicated in the research and case studies discussed in Chapter 1, seagrasses are particularly vulnerable to high levels of suspended solids in the water column, and excessive epiphyte and phytoplankton growth caused by high nutrient levels. Both lead to more rapid light attenuation with depth, and this inhibits seagrass photosynthesis (Bulthuis 1983). Bulthuis (1983) found that *H. tasmanica* requires about 5% of the surface light intensity to survive. In clear ocean water this threshold can be over 15 m, but as phytoplankton and suspended particle levels increase the depth is correspondingly reduced. For example, the maximum depth at which the species was found in the tannin-stained water of Port Davey/Bathurst harbour in Tasmania's South West is 2.5 m (see Chapter 5).

(b) Temperature

Seagrasses are typically able to survive fluctuations in temperature experienced in coastal areas such as lagoons and estuaries (Zieman & Wetzel 1980). Seagrasses in Tasmania growing in intertidal habitats, in particular *Zostera muelleri*, must withstand temperatures as low as 0°C in winter and higher than 35°C in summer when exposed. *Heterozostera tasmanica* and *Halophila australis*, occuring subtidally experience a smaller temperature range. It is doubtful that temperature is a limiting factor in the distribution of these species in the State.

Ducker *et al.* (1977) suggest that a simple relationship between temperature and the distribution of *Amphibolis antarctica* is unlikely, although it is considered an important factor. The genus is found within a zone of mean maximum temperatures of 16-25°C and mean minimum temperatures of 10-22°C. The coastal water of oceanic origin in Tasmania falls within these limits (Edwards 1979).

Posidonia australis may be limited to the North Coast of Tasmania by temperature. The lack of suitable habitat on the East Coast between Eddystone Point and the Freycinet Peninsula may present an insurmountable geographic barrier to a more southerly establishment of the species, although *Amphibolis antarctica* is found at Coles Bay and Maria Island in situations apparently suitable for *P. australis*, and may have migrated down the east coast to those sites.

(c) Water energy

Seagrasses are generally unable to establish and survive high levels of kinetic water energy, and are not found where there is heavy wave action, persistent large swells and strong currents. The level of resilience varies from species to species (Clarke & Kirkman 1989). From observations of the species found in different Tasmanian coastal formations in this study, a hierarchy of tolerance to water energy is suggested. This is, beginning with the most tolerant:

(1) *Amphibolis antarctica*
(2) *Posidonia australis*
(3) *Heterozostera tasmanica*
(4) *Zostera muelleri*
(5) *Halophila australis*

Freak storm events may also cause extensive damage to seagrass communities in sheltered areas. Additionally, the mechanical modification of flow patterns and wave protection by coastal engineering or dredging can have severe consequences for seagrass beds.

(d) Sediment

The nature of the sedimentary substrata in which seagrass root systems and rhizomes grow varies from coarse sand to mud. There is little reference in the literature to the importance of particle size to seagrasses, and, as has been superficially explored in this study, most species appear to tolerate a range of sediment types (see Chapter 5). As with terrestrial plants, the sediment provides not only a medium in which to anchor, but also a substratum in which complex chemical and microbial processes occur related to nutrient and gaseous recycling. The oxygen and nutrient availability, and microbial activity within sediments have effects on seagrass productivity (Hillman *et al.* 1989).

(e) Salinity

Seagrass species have preferred salinity ranges. For example, in Shark Bay, Western Australia, it has been demonstrated that salinity has a controlling influence on the distribution, productivity and biomass of *Amphibolis antarctica*. The densest cover of this species in that region occurs at salinities of 40‰ to 50‰ (Walker 1989). It is rarely found in estuarine environments. Conversely, a sensitivity to lower or higher salinities may prevent the establishment of a species in otherwise suitable habitat. Although no readings of salinity were made in this study, the ability of the species *Zostera muelleri* to survive in the upper regions of many estuaries suggests that it has a greater tolerance of mixohaline conditions than the other four Tasmanian species.

2.3.2 Habitat Classification

Much of the coastline of Tasmania, is exposed to high wave energy. This may be on a regular or seasonal basis, such as on the west coast, or through the occasional storm event, as on the east coast. In general, wave energy limits seagrasses to habitats in estuaries and sheltered embayments (West *et al.* 1989), although extensive beds may occur at depth offshore beyond the influence of high energy waves. A classification of coastal habitats is useful for describing seagrass distribution.

Other projects have taken a variety of approaches to this issue, reflecting the diversity of seagrass habitats in their study area. Shepherd & Robertson (1989) categorised coastlines into three habitat types based on coastal topography. These are:

(a) exposed coasts,
(b) gulfs and bays (including estuarine habitats), and
(c) coastal lagoons.

Shepherd & Robertson (1989) acknowledged that factors such as water movement and wave energy, turbidity and light, temperature, salinity, sediment characteristics and desiccation may vary considerably within these three habitats. A classification that reflected these factors would be very complex, and require sampling far beyond the scope of this study.

In discussing the distribution of mangroves and seagrasses on the New South Wales coast, West *et al.* (1989) describe the coastal formations of:

(a) barrier estuaries,
(b) drowned river valleys,
(c) open embayments, and
(d) saline coastal lakes.

The occurrence of seagrasses outside these formations is uncommon in NSW. In a statewide survey, West *et al.* (1985) included coastal lagoons in the classification and further assessed the maturity of the water body in terms of the degree of infilling. The status of the entrance was also recorded, whether open to the sea, intermittently open or closed, or primarily closed, and if it had been mechanically opened or training walls constructed.

2.3.3 Studies classifying Tasmanian coastal habitats

Tasmania has a wide variety of marine coastal habitats. A number of studies have attempted a classification of the Tasmanian coastline suitable for their particular goals. Two such works (Mollison 1963; Last 1983) have focussed on inshore and estuarine fish habitats, and these are relevant to seagrass habitats in the State.

A classification of river estuaries and coastal lagoons in Tasmania was proposed by Mollison (1963). He divided these areas into three groups:

(a) those permanently open to the sea (bay estuarine waters, coast estuarine waters, and tidal arms);

(b) those dammed by sand, breaking open to the sea irregularly (bar dammed rivers, bar dammed lagoons, beach dammed rivers); and,

(c) waters not connected to the sea (eutrophic dune lakes and inland saltpans).

The first two of these groups cover the majority of seagrass communities in the State. However, Mollison confined the study to areas upstream of a true marine environment in terms of salinity, and did not survey bays or offshore areas. He recorded seagrasses in a number of locations.

Last (1983) made a more detailed categorisation of the Tasmanian coastline, focussing on sedimentary environments. He recognised three basic geomorphological types, which were further sub-divided into 55 minor habitats. These were based on the criteria of exposure, substrate characteristics, topographic position, geomorphology, bathymetry and hydrology. The three major categories described are:

(a) closed or semi-closed drainage systems (including coastal lakes, bar-dammed lagoons and rivers, and beach-dammed rivers);

(b) open drainage systems (including open lagoons, bay estuaries, and tidal rivers and creeks); and,

(c) beach systems (including sheltered, semi-exposed and exposed beaches).

This work (Last 1983) was directly concerned with soft-bottomed habitats in Tasmania. Seagrasses are also confined to these habitats, and the same major categories have been broadly adopted here. Last's study was further limited to the 'shore zone', for which the lower limits were taken as 50 m offshore from mean low water spring (L.M.W.S.) or the 6 m depth level below L.M.W.S. (Last 1983). Although many seagrasses in Tasmania are found within that zone, there are extensive communities that are either further offshore, and/or at a greater depth. Those limits of distance and depth have not therefore been adopted, and modifications to the range of habitat types have been made to include these communities.

2.3.4 A coastline classification adopted in this study

It was decided to use a relatively simple 11 point classification of coastal areas based on exposure and geomorphology, illustrated in Figure 2.3. The minor classifications presented by Last (1983) have not been adopted since parameters such as the bathymetry and substratum are included in the sample site data, and the topographic position of the seagrass communities is indicated on maps (see Chapter 5). Only the hydrographic information of salinity and light attenuation has been excluded from both the sampling and habitat classification, although regional trends are described in section 2.2. The maturity of coastal formations has not been assessed as in West *et al.* (1985), and, since mechanical opening of otherwise closed systems is uncommon in Tasmania, and training walls are rare, these are included in comments on individual sample areas (see Chapter 5 & 6).

The 11 major habitats and their numerical codes are:

Closed or Semi-closed drainage systems

(1) coastal lakes
(2) bar or beach dammed lagoons
(3) bar or beach dammed rivers

Open drainage systems

(4) open lagoons
(5) estuaries
(6) tidal rivers, creeks and tributaries
(7) tidal arms

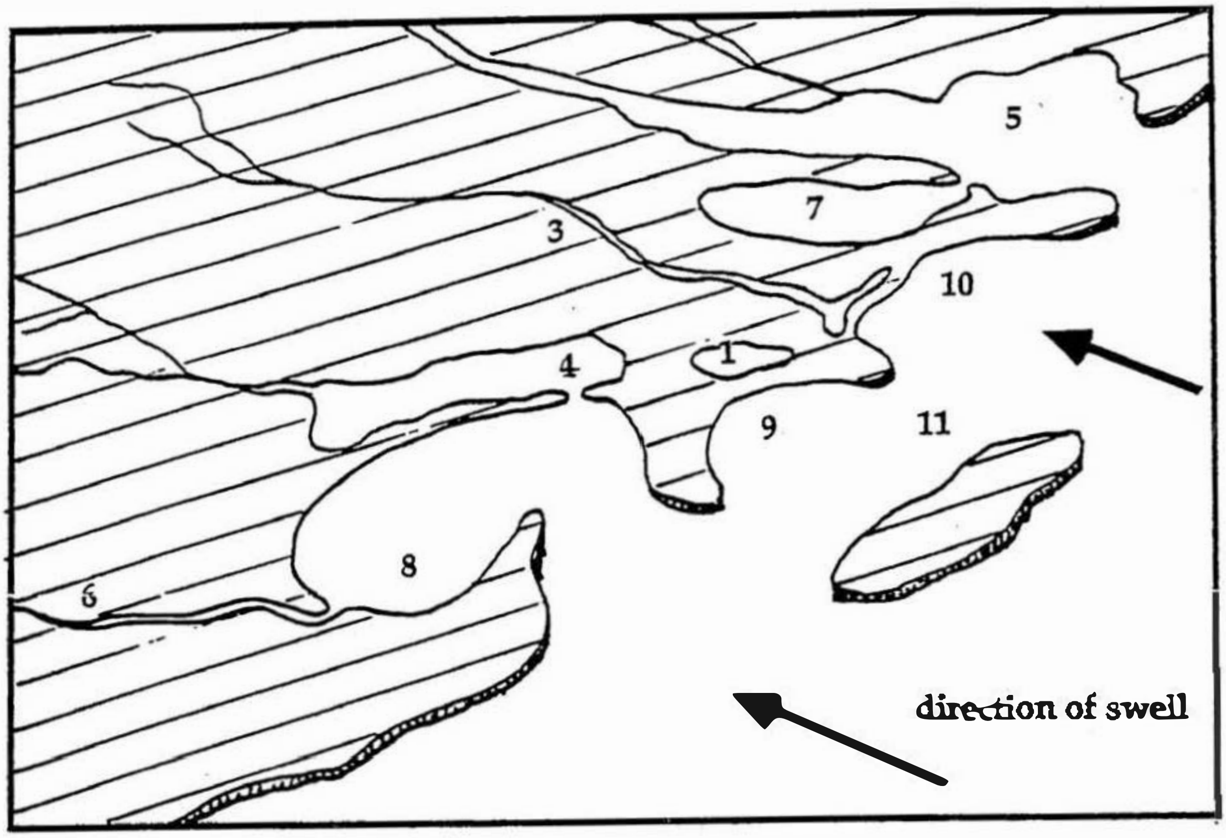
Beach/bay systems

(8) sheltered beaches
(9) semi-exposed beaches
(10) exposed beaches

Other areas

(11) straits and channels.

Figure 2.3:
Major types of coastal landform and codes adopted in this study (after Last 1983).



Key to coastal formations

1 coastal lakes
2 bar or beach dammed lagoons
3 bar or beach dammed rivers
4 open lagoons
5 estuaries
6 tidal rivers, creeks and tributaries
7 tidal arms
8 sheltered beaches & bays
9 semi-exposed beaches & bays
10 exposed beaches & bays
11 straits & channels

2.3.5 Description of habitat types

The following descriptions of the habitat categories adopted in this study are derived from Mollison (1963) and Last (1983). Comments on the occurrence of seagrasses have been added by the author:

Closed or semi-closed drainage systems

Although occasionally open to the sea by channels or overflows, these estuarine and freshwater basins are usually closed by sedimentary barriers. They range from being permanently closed to permanently open, varying over time, and include:

(1) coastal lakes - these are not connected to other drainage systems and include basins, such as saltpans, and dune lakes. No coastal lakes have been sampled in this study, though it is possible that some contain isolated communities of *Zostera muelleri*.

(2) bar or beach dammed lagoons - these estuarine systems are brackish, with salinity increasing over the time since their last closure. This may be a number of years in some cases. They are often deep, and can be highly productive ecosystems. Communities of *Ruppia* spp. and *Zostera muelleri* often occur in shallow areas of these lagoons. Examples include Big Lagoon and Dianas Basin on the east coast.

(3) bar or beach dammed rivers - these may drain through seepage channels over the bar or beach, and be penetrated by sea water over the same barrier during storms. Their salinity is generally low. *Zostera muelleri* and species of *Ruppia* may occur in the shallows. Only Scamander River has been sampled in this study. The Nelson and Thornton Rivers on the west and south coasts are other examples.

Open drainage systems

These permanently open estuarine systems vary in width, depth and flow characteristics considerably, and are mostly brackish.

(4) open lagoons - these are often very large tidal lagoons with extensive shallows and channels less than 4 m deep. Examples are Pittwater in the south, Great Swanport and Mussel Roe Bay on the east coast, and North East River on Flinders Island. *Zostera muelleri* commonly forms beds in shallow areas and intertidal flats, and *Heterozostera tasmanica* may be found in the channels, particularly close to the entrance where a wedge of seawater penetrates.

(5) estuaries - most of the major estuarine systems in Tasmania fall within

this category, including the Tamar and Mersey Rivers and Port Sorell on the north coast, the Derwent and Huon Rivers in the south, and Macquarie Harbour and Port Davey on the west coast. They all possess wide embayments, and, especially in the northern rivers, may have a number of tidal channels and exteniveflats exposed at low tide. Their suitability as seagrass habitat has usually been modified by human activity, but also varies greatly within this category with the wide range of salinities, temperatures and light attenuating materials that occur. All five Tasmanian seagrass species occur in the Tamar River estuary on the north coast.

(6) tidal rivers, creeks and tributaries - these possess no extensive widened sections or embayments, and as a result have surface salinities generally much lower than euhaline (marine) conditions, although deeper systems may have salt wedges. The flow rates of fresh water are often very high, especially on the west coast, and salinities in adjacent coastal areas may be seasonally affected for some distance. Larger examples include the Arthur and Pieman Rivers on the west coast, and the Forth and Emu Rivers on the north coast. Seagrasses do not favour the low salinities and high flow rates of such environments, but *Zostera muelleri* may be found on small intertidal flats and *Heterozostera tasmanica* on the banks of channels near the mouth of these rivers and tributaries.

(7) tidal arms - these are often large shallow basins with little drainage from the surrounding catchment, and are therefore essentially marine. They are open to estuaries or bays and are inundated at each tide with seawater. Examples include East and West Inlets near Circular Head, Kelly Basin in Port Davey, Pipe Clay Lagoon near Hobart, and Blackman Bay on the southern east coast. Such areas are a suitable habitat for *Zostera muelleri* and *Heterozostera tasmanica,* which may form large meadows.

Beach/bay systems

These include beaches and hard-rock coasts, and can be classified according to their degree of exposure to wave energy, although each site is unique and the range of conditions is infinite. Their exposure will depend on the prevailing wind strength and direction, the length of wind fetch, local currents, and, exerting influence on all these, the morphology of the local landforms and the presence and nature of any offshore protection.

(8) sheltered beaches/bays - these experience low wave energy exposure being enclosed within bays, or protected by islands or reefs. Fetches are short. There are often extensive intertidal flats and shallow subtidal

areas which may have large stands of seagrass. All Tasmanian species may be found in such locations, varying from region to region. The ria coast of the south east of the State has many such habitats, for example the beaches of the north coast of the Tasman Peninsula from Lime Bay to Cascades Beach. *Heterozostera tasmanica* and *Halophila australis* abound in this area, with *Zostera muelleri* occuring intertidally.

(9) semi-exposed beaches/bays - these areas receive some protection from headlands or reefs, and are characterised by exposure to moderate wave action at least sporadically. They may receive swells by wave refraction or reflection. Seagrasses found in such conditions include *Amphibolis antarctica* and *Heterozostera tasmanica*, particularly on the north coast, facing Bass Strait.

(10) exposed beaches/bays - these may experience direct continuous ocean swells as on the west coast, or less frequent swells as on the east coast. Either set of conditions, and any intermediary ones, are too destructive to allow seagrasses to establish, although *Heterozostera tasmanica* may be found in deeper water offshore.

Other areas

(11) straits and channels - these pass between landmasses such as islands to connect two larger bodies of water. They vary considerably in depth and width, but may have large relatively shallow areas that support extensive communities of seagrasses such as *Posidonia australis* and *Heterozostera tasmanica*. Examples include the Mercury Passage, Robbins Passage, Franklin Sound and Waterhouse Passage.

In the field sampling for this study each coastal area has been assessed within this 11 point category. Sometimes more than one coastal formation has occured within a sample area, and this is reflected in the habitat type attributed to each sample. A complete list of sample areas and their coastal classification, and maps indicating their locations are included in Chapter 4 (Maps 4.1 to 4.4; table 4.1).

Chapter 3.
SEAGRASS MAPPING

This project is concerned with mapping the distribution of seagrass communities around the coast of Tasmania. In selected areas, the mapping covers three time periods spread over more than forty years. To achieve this goal, reference was made to the literature on remote sensing, the mapping of seagrasses and other vegetation, and to previously published seagrass surveys. Other workers in this field were also consulted. The most appropriate techniques and technologies were adopted within the constraints of the time and resources available, and the size of the area to be covered.

This chapter looks at the literature on the surveying and monitoring of seagrasses. It also considers the issues of vegetation boundaries applied to seagrass communities, and discusses the concept of a Geographic Information System (GIS), and its fuction in mapping and data management in this project.

3.1 Seagrass mapping - an overview

In the last two decades there have been numerous Australian and overseas studies that have mapped seagrass communities in conjunction with the measurement of other parameters (VIMS 1989). Although very small areas of seagrass can be mapped by field sampling alone, to do the same for large stretches of coastline would be prohibitively costly, and in such cases some form of remote sensing is usually employed. Shallow water environments can most efficiently be surveyed from an aerial platform from which images of the distributional patterns of the vegetation can be recorded (Kelly 1980).

This section looks at techniques for the essential field sampling, or ground truthing of remotely sensed seagrass communities, and then outlines the major issues relating to different remote sensing technologies.

3.1.1 Field survey techniques

Any means of mapping underwater vegetation using remotely aquired data must be complemented by a field sampling program to 'ground truth' or validate the images (Orth & Moore 1983). 'Ground truth' parameters can be defined as those ground features that generate the signal recorded by a camera or scanner through the atmosphere (Lintz *et al.* 1976).

The initial aim of ground truthing is to verify that an underwater feature is indeed a seagrass bed, and not objects such as macroalgae, mollusc beds or rocks. For example, in some areas off Adelaide, South Australia, macroalgae such as *Ulva* spp. have been found using the root mat of dead *Posidonia* beds as a substratum, and can be confused with healthy seagrasses in aerial photography (V. Neverauskas, pers. comm.). Similarly, Lo and Crowell (1992) mapping seagrasses from aerial photographs in Florida in 1990, found that their 1988 maps had included areas of algae.

While sampling, important parameters not accessible through remote sensing can also be recorded. These might include the species composition of the communities, their depth, the substratum, measurements of the biomass of the seagrasses and the extent of epiphyte growth. However, sampling strategies have often been poorly designed, leading to difficulties in linking their results to existing databases and later research (VIMS 1989).

3.1.1.1 Position fixing

An accurate means of fixing the position of sample sites is important in mapping seagrass beds at any scale (VIMS 1989). The need to be able to monitor slow changes in decline or recovery of seagrass beds ideally requires an accuracy of 1-5 m in fixing the position of boundaries and sample sites. This level of accuracy can be achieved using current surveying techniques, but may present cost and resource problems in projects covering larger areas.

Optical means of position fixing available include the marine compass, the theodolite or sextant. Electronic methods include radar, satellite navigation or a Global Positioning System (GPS). The expense and error of earlier GPS technology is being overcome with the evolution of lower cost hand held GPS receivers capable of giving positions to accuracies of a few metres (GIS User 1992). This should make accurate, rapid position fixing accessible to projects such as this in future, although this approach was not available in this survey.

Optical technologies vary in cost and ease of deployment. A theodolite used in conjunction with an electronic distance measurer will give accuracies to ± 1 m. This combination is best suited to locating permanent positions such as transects for small project areas covering individual bays or estuaries. A sextant in the hands of a skilled operator will give a ± 5 m accuracy, and requires three accurately fixed locations in the area to achieve this (VIMS 1989).

The simplest, cheapest, but least accurate method is the marine compass. This requires two visible landmarks to derive a position fix, and accuracies of ± 20 m in inshore areas, declining to ± 100 m offshore can be expected. In small estuaries and bays, with clear landmarks and reference to aerial photographs and charts for bathymetry, simple line-of-sight observations can be made to similar accuracies using two or more pairs of landmarks. Although such inaccuracies may seem excessively large, they must be compared to errors generated when mapping from aerial photography. An object of 0.5 mm on a 1:25 000 aerial photograph is equivalent to 12.5 m on the ground, and on a 1:40 000 photograph the same sized object is equivalent to 20 m on the ground. Photograph scales of these magnitudes are common in recent and archival aerial photographs in Tasmania.

Electronic methods, such as radar and satellite navigation, have a range of accuracies, and vary considerably in cost and ease of use (VIMS 1989). These were not used in this survey.

3.1.1.2 Sampling strategies

Sampling strategies must be tailored to the outcome sought. They range between a qualitative observation of the species present, with possibly a coarse assessment of density, to quantitative approaches where biomass and other parameters are measured.

Qualitative methods seeking to give a measure of seagrass abundance tend to be subjective. They require clear definitions to be of use for later research. Relative estimates of percentage cover allow some quantitative analysis of the data, although the possibilities for such analysis are limited to non-parametric or ranking tests (Orth & Moore 1983). Percentage cover can be estimated in the field, or from remote imagery such as aerial photographs. Field estimates offer more scope for accuracy, such as measuring the distance beween shoots to calculate shoot density. Estimation of the percentage cover from aerial photographs allows consistency in comparing different time periods, and is less expensive for large projects, though it is less accurate than field measurements (see Section 3.3.1).

Quantitative methods include establishing transects, and various random sampling strategies. Transects give an accurate measure of vegetative change in a seagrass community along an environmetal gradient, such as salinity or depth. They can be sampled by SCUBA, by a remote vehicle, or more superficially from the surface using a periscope, grab or dredge. Underwater photography or video recording can be employed, or, if SCUBA is used, direct observations can be recorded on a tablet. Many studies have used transects (for example: May *et al.* 1978; Orth *et al.* 1979; Neverauskas 1987a; Kirkman *et al.* 1988; Hillman *et al.* 1990), and the establishment of permanent transects using markers embedded in the sediment is recommended for long term studies of biomass or boundary change (H. Kirkman, pers. comm.).

Random sampling is useful for detailed studies of an area, and can be refined by using a stratified sampling approach where homogeneous sub-sections of the overall area are each randomly sampled (Orth & Moore 1983). These authors cite Bulthuis (1981) as an example of the use of stratified random sampling. He divided the study area of Western Port, Victoria, into 25 recognisable strata subdivided into sites that were then randomly sampled. In all random sampling approaches, the statistical issues of the size of each sample and the number of samples taken must be balanced against the cost and effort required to attain increased statistical significance.

3.1.1.3 Sampling apparatus

This section is concerned with physical means of sampling of seagrass vegetation. For some methods of measuring distribution, productivity and density, the physical removal of material from a community is not necessary. If using SCUBA or snorkelling, quadrats can be surveyed, and many parameters can be measured directly and non-destructively. These include species identification, density, leaf blade dimensions and growth rates, estimates of epiphyte coverage and substratum data. Measurements of the biomass of seagrass or epiphytes by dry weight necessarily requires the removal of shoots and rhizome material.

If working from the surface, other means must be used, which involves apparatus designed to retrieve a sample. If samples are required solely for qualitative assessment, the reliability and performance of the sampler is not as important as for quantitative sampling (Eleftheriou & Holme 1984). For the latter, a corer that takes a plug of the vegetation and sediment is more reliable than a grab, which can become snared with long seagrass leaves and fail to reach the sediment and seagrass roots. A corer delivers a sample of consistent surface area, important for statistical analysis (Orth & Moore 1983). The sample size is commonly 0.1 m^2. However, the apparatus needs to be heavy to penetrate the sediment and seagrass root mat, and requires a mechanical means of release and retrieval.

If only species identification is needed, qualitative sampling from the surface can employ a small dredge. In the case of Tasmanian seagrasses, where the small number of subtidal species can be easily identified from vegetative shoot material, a grab or dredge is adequate. However, it is often necessary to obtain a sample of root material to distinguish between *Heterozostera tasmanica* and *Zostera muelleri*, and an efficient, light-weight and relatively non-destructive apparatus is required. For this study, a modified double-sided anchor dredge was constructed (see Section 4.2).

3.1.2 Remote sensing

Due to the shallow marine and estuarine habitat of seagrasses, the community boundaries can often be seen against the substratum from an elevated aerial vantage point. This platform is usually an aircraft or satellite, and the remotely sensed images may be recorded digitally by multispectral scanner, on photographic film, or on video tape. Each of the various methods of remote sensing has advantages and disadvantages in terms of resolution, scale, water penetration, colour spectrum, and cost. As previously discussed, however, images must be verified or ground-truthed by field observation regardless of the means of data capture (VIMS 1988).

3.1.2.1 Satellite Imagery

Some recent studies have employed satellite imagery such as Landsat TM and SPOT (Greenway & Fry 1988; Monaghan & Williams 1988; Lennon & Luck 1990). The units of ground information, or pixils, captured by these multispectral scanners are 30 m^2 for Landsat TM and 20 m^2 for SPOT (multispectral). These are considerably higher resolutions than the earlier Landsat MSS images of 60x80 m.

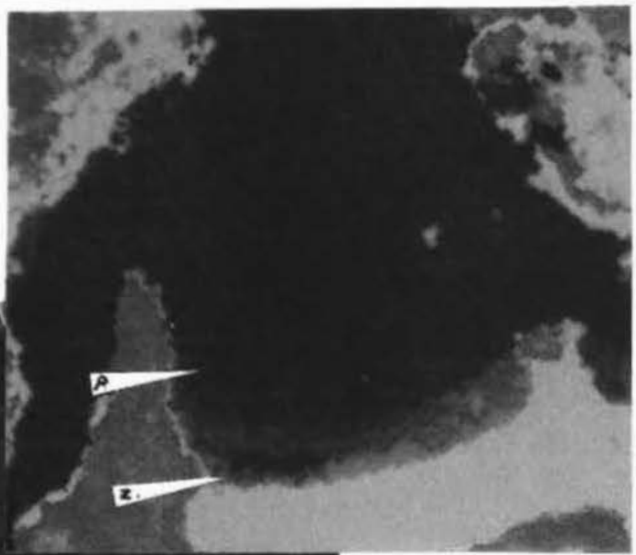
With computer manipulation of the different wavebands in the captured images, the unique light spectra of different seagrass species can be used for identification and mapping. Similarly, the epiphyte loading on the seagrass leaves can in some cases be quantified from digital images (V. Neverauskas 1991, pers. comm.). Similar multispectral scanners mounted on light aircraft also show some promise due to the greatly reduced pixil size. The maximum spatial resolution approaches 2 m^2 giving an equivalent accuracy to small scale aerial photography (VIMS 1988).

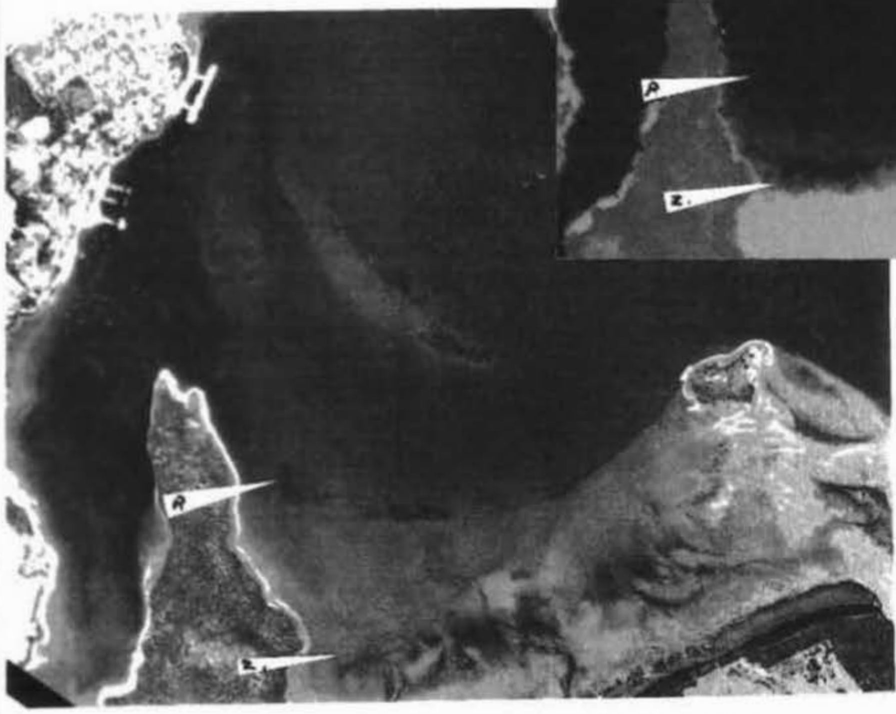
Apart from the large pixil size of satellite imagery, there are a number of other disadvantages to this type of data capture. The infra-red wave-band which will detect radiation from the chlorophyll in submerged vegetation is readily absorbed by seawater, and there is little useful penetration beyond 2 m depth, even in clear water. Greenway and Fry (1988) found that the area of seagrass beds was underestimated using SPOT images, suggesting that deeper areas were not detected. This type of remote sensing is therefore only suitable for shallow seagrass habitat, and the scans must coincide with low tide to achieve useful results. Additionally, archival scanned images are only readily available since 1972 for Landsat MSS, 1986 for Landsat TM, and 1990 for SPOT (Bleys *et al.* 1991).

Plate 5:

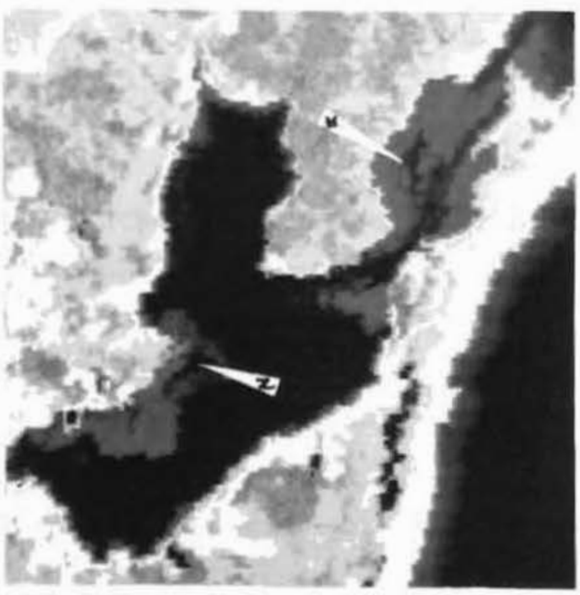
Examples of landsat imagery indicating seagrass beds

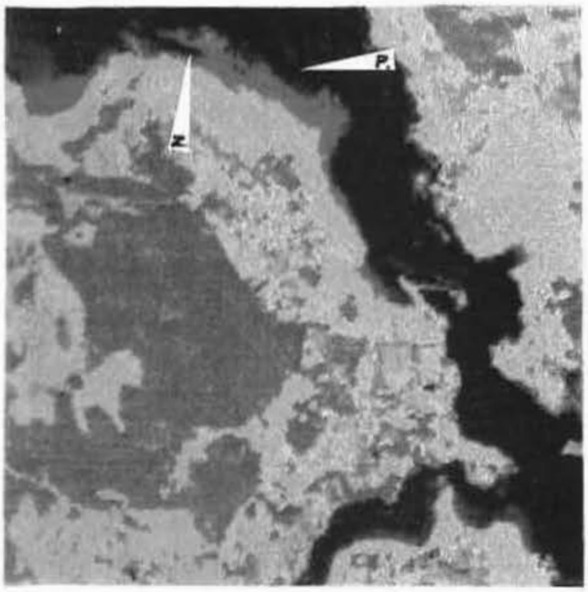
Aerial photograph and Landsat MSS images of the Tamar River near Beauty Point showing *Posidonia australis* and *Zostera muelleri* beds





Landsat MSS image of Georges Bay, east coast of Tasmania, showing shallow seagrass beds (below)





Landsat MSS image of the Mouth of the Tamar River, and Greens Beach, north coast of Tasmania, showing shallow *Z. muelleri* and *P. australis* beds

Historical comparisons are therefore very limited compared to archival aerial photography, although they will become more valuable in this regard in the future.

In support of satellite remote sensing is the lower price of images prior to any enhancement, estimated at around 1/30th the cost of aerial photography, or (at 1988 prices) 18¢ per linear kilometer (VIMS 1988). Landsat MSS and TM imagery was investigated for this project and scans of some coastal areas were compared with field sampling data (see Plate 5). Some shallower seagrasses were detected in the three locations studied, but the approach was rejected in favour of aerial photography on grounds of improved resolution, water penetration and more extensive archival coverage.

3.1.2.2 Aerial Photography

"Aerial photography remains the most accurate technique (for detailed vegetation mapping), and provides a source of historical data because much of coastal Australia adjacent to urban centres has been photographed since the mid 1930's" (Clarke and Kirkman 1989)

Aerial photography is the most frequently used remotely sensed data for seagrass mapping. Under ideal conditions, features as deep as 16 m can be mapped (Campbell 1987). Many projects world-wide have used it to map species distribution and boundary changes in seagrass communities. Quantitative measurements of the areas of seagrass beds can be generated electronically from scanned or digitised maps derived from aerial photographs using suitable computer software, or manually by counting squares on graph paper or using a planimeter (Kirkman *et al.* 1988) Using any of these techniques, a comparison of a time series of maps for a given area will give a quantitiative estimate of changes in seagrass coverage (V. Neverauskas 1991, pers. comm.). Some Australian examples include studies from New South Wales (e.g. West *et al.* 1985; Larkum and West 1990), Western Australia (e.g. Cambridge and McComb 1984) and South Australia (Neverauskas 1987b).

Survey results are presented as maps, with scales ranging from 1:1000 to 1:50 000 depending on the project's resources. Cost is an important consideration, and more detailed sampling and higher definition mapping are generally only possible on projects studying limited areas (e.g. Kirkman & Reid 1979; Neverauskas 1987b; Greenway & Fry 1988). A survey of the N.S.W. coastline looking at seagrass and mangrove distribution sampled a comparable number of sites to this Tasmanian study, and chose a map scale of 1:25 000 (West *et al.* 1985).

There are combinations of environmental factors that make the remote sensing of underwater vegetation difficult or impossible in some circumstances. Wind disturbance must be minimal, and recent conditions should preferably have been calm and dry, leading to minimum turbidity through wave action and runoff. High levels of phytoplankton, tannins or suspended solids in the water may obscure benthic features, and the sun's elevation at the time of image capture may reflect directly off the water surface. These factors are not so relevant for photography of terrestrial features, yet can render a photographic series useless for detecting benthic features. In the case of archival photographs this may cause a significant gap in the time series for a particular location. Additionally, because light attenuation in water can vary considerably, the deeper boundaries of seagrass communities are often difficult or impossible to distinguish.

Other problems arise in interpreting benthic features off photographs. Estimates of density become difficult as seagrass beds increase in depth because the tone darkens, and contrast with the surrounding substratum and water decreases. Also, deeper basins in the substratum may be indistinguishable from seagrass beds. Detritus from seagrass leaves and macroalgae also poses interpretation difficulties as it may appear identical to live seagrass (Kirkman *et al.* 1988).

Flights can be specifically tailored for photographing benthic communities. Various recommendations are offered by different researchers. One suggestion for ideal conditions under which to photograph seagrasses is from low altitude, at times of low cloud cover, at low tide and with the sun near or at its zenith (FAC 1992). Generally, however, cloud cover is not recommended by researchers as shadows can be confused with seagrasses. Kirkman *et al.* (1988) used photographs taken on a cloudless day with a sun angle 45°. Orth and Moore (1983) suggest clear skys with a sun angle of 20° to 40° to minimise surface reflectance, and Lefevre *et al.* (1984) provide formulae for optimising picture quality at different periods of the year given the changing sun angles. They also give guidelines on selecting the most appropriate optical filters for monochrome photography to enhance vegetation and contrast under different conditions.

Colour aerial photographs can give better water penetration and easier identification of species than monochrome images, although they are not as suitable for spectrally based analyses of species and epiphyte cover as satellite images (Bleys *et al.* 1991). In Tasmania, aerial photograph projects in colour are only available from the early 1980's onwards, and for cost reasons the Department of Environment and Planning generally only holds prints in black and white of these projects. Colour prints must be ordered specially and are expensive. Thus, although they may reveal useful additional information of the benthos, they have been little used in this project.

Examination of aerial photographs over a time series can reveal boundary movement, changes in area and density. There are often problems in having to use photographs of different scale and quality, and these must be acknowledged in presenting results. Additionally, archival photographs obviously cannot be ground truthed, although oral histories and earlier research references can be useful substitutes.

A further problem in the use of photographs are their inherent distortions. These are due to slight changes in the attitude and height of the aircraft, lens distortion, and a progressively increasing angle from vertical of features from the centre to the edge of the photograph. These factors lead to the need to transform photographs by optical or digital means in order to match adjacent photographs into mosaics. This can be achieved by GIS software such as ARC/INFO™ or Adobe Photoshop™ (Bleys *et al.* 1991). If such transformations are not possible, it is considered that errors are acceptable if only the central 1/3rd of a photograph is used.

3.1.2.3 Aerial video photography

Recent technology has enabled the capture of detailed analogue images from video tapes taken from aircraft. The costs involved are very favourable compared to other forms of remote sensing. Since many hundreds of images are taken in the course of a transect, the most suitable ones can be chosen and processed to overlay on real-world coordinates. Such processing can be carried out on modest desktop computers. This technology promises to provide a means of regular monitoring and updating of seagrass coverage and other areas of environmental concern.

3.1.3 Geographic Information Systems (GIS)

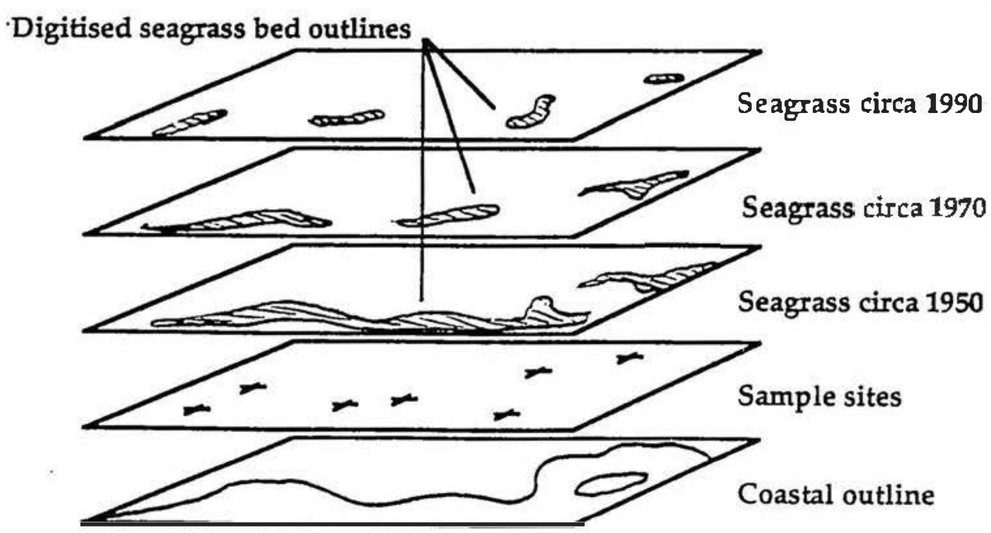
A GIS can be described as a computer based system capable of capturing, storing, checking, updating, integrating, manipulating, analysing and displaying all forms of geographically referenced information (ESRI 1990; Board 1991). A GIS allows a relational database to be attached to map information, and can be manipulated to graphically represent interelationships between different sub-sets of the database. Data is added in 'layers' to a base map, and, once a GIS is established, the number of layers of data that can be added is only limited by the capability of the computer hardware and software to handle it. As with any database, however, the quality of the output can only be as good as the quality of the input.

When mapping seagrass communities, data on the species composition, their density, depth, the coastal geomorphology, the location of sample sites for ground truthing and any other parameters, can be referrenced to the mapped outlines of seagrass beds, to sample sites and the base map. The outlines of the seagrass beds from different times can be overlayed onto this base map as separate layers, and likewise the sample sites (see Figure 3.1). In this project the base map is the coastal outline of Tasmania, digitised at 1:25 000.

Each sample site has a unique identity and is related to a data base which carries the values for the measured parameters of all sites. Once entered, the data can be manipulated and cross referenced to generate a desired output. For example, the areas of the beds can be calculated and compared between different times thus providing a measure of any changes in the coverage of seagrasses in a particular place, or over the whole State. The areas occupied by different species can be obtained, and again changes over time calculated. Similarly, the occurence of a given species can be related to the type of coastal area, substratum or depth. These data analyses can be viewed on a screen at any window size, and produced as hardcopy maps at any scale to suit particular needs.

Figure 3.1

ARC/INFO: layering of data related to the coastal outline base map

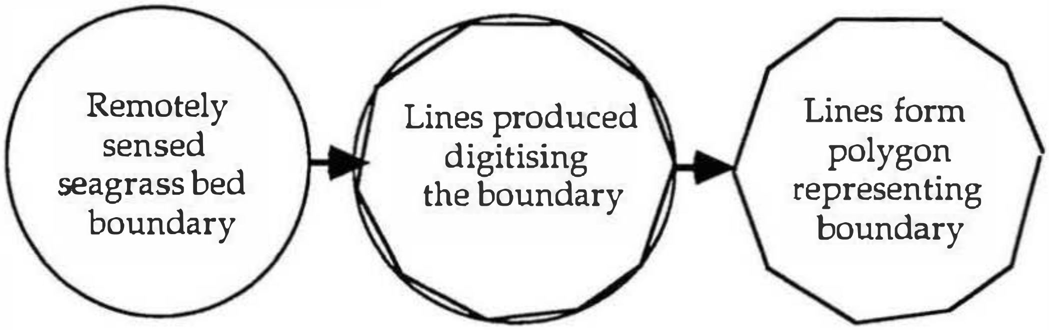


Other layers of data can later be added to the GIS. These may, for example, relate to human activity in related catchments such as industry, waste disposal, logging, urban development or agriculture; layers detailing water based activities can be added including fishing, aquaculture, dredging, moorings and anchorages. Climatic data may be relevant including water temperatures, currents, prevailing winds and swells. For example, Lo and Crowell (1992) mapped seagrasses in Tampa Bay, Florida, within the context of a broader coastal GIS aimed at water quality improvement, habitat protection and restoration, and fisheries management. The resulting seagrass maps form one layer in the district's GIS map library.

A number of software packages are available for generating a GIS. Data bases can usually be transferred between these different systems. ARC/INFO was selected for use in this study due to its data storage and analytical capabilities, and because of the high level of expertise in its use at the Centre for Spatial Information Studies (CenSIS) at the University of Tasmania. ARC/INFO is a vector based program in which a GIS is constructed using a data model common to many other systems. Both a topographic model, which describes point, line and area features, and a relational model, which describes the characteristics of these features, are used are used in organising the geographic data (Peuquet & Marble 1990). The location of data on a map is represented by points, lines or arcs, and enclosed areas or polygons.

A polygon can be drawn from an aerial photograph to represent the relative size and shape of a particular seagrass bed. Seagrass bed outlines can be traced off the photograph on a digitising table. This manual process sends a series of signals that digitally describe the coordinates of points along the outline, generating an approximation of the boundary. This outline is thus made up of a series of short lines forming a polygon (see Figure 3.2). The skill of the operator is important, but outlines can be followed with the digitising cursor with an accuracy of ± 0.5 mm.

Figure 3.2:
Diagram illustrating digitised outline of seagrass bed produced from remotely sensed image.



3.2 Mapping seagrass community boundaries

"All boundaries are arbitrary, distinctions drawn in space by the observer. Nevertheless, we find that many observers distinguish similar boundaries, which are commonly accepted as useful." (Canny 1981, p.1)

Establishing the boundaries of seagrass communities for mapping purposes poses many problems (A number of examples of seagrass bed boundaries in Tasmania are reproduced on Plate 6). Despite this, however, the issues of boundaries and boundary errors receive little attention in the literature on seagrass mapping. Many studies have been concerned with measuring decline in seagrass beds (see Section 1.4), and have been involved in detecting boundary changes, yet the criteria by which decisions on the positions of boundaries are made are not described. This is surprising since, for example, in many situations seagrass beds become very sparse at their outer edges, and may also be complex and convoluted in shape. On aerial photographs such boundaries may blend indiscernibly into the surrounding substratum, or be invisible due to physical conditions prevailing at the time.

Boundaries have been defined as systems, or zones, separating two adjacent systems. Where a boundary is a sharp or abrupt line rather than a zone, it represents a special case of a zone containing no elements and with one dimension reduced (Maarel 1976). In the marine environment, seagrass beds and the surrounding substratum can be considered adjacent systems with a variety of physical and biotic interactions across their common boundaries.

Ecological boundaries tend to be sharpest in a vertical plane where factors such as gravity and light have a strong influence, for example at an air/water interface. This is relevant to intertidal seagrasses. In addition, because light attenuates rapidly in water, marine plants have very narrow depth zones compared to the corresponding altitude zones in terrestrial vegetation (Kuchler & Zonneveld 1988). On steeply sloping substrata this gives rise to small or narrow seagrass beds, which may have dimensions smaller than the accumulative error of the system used to map them.

On level surfaces the influence of gravity and light are relatively constant. Here, horizontal boundaries tend to reflect the weaker interactions between neighbouring communities, and within the communities themselves (Canny 1981). Within a community on a level substratum, complex and dynamic internal boundaries may develop in response to interactions between the community members.

Plate 6:
Aerial photographic examples of seagrass bed textures and boundaries

Blowouts in *Posidonia australis* and diffuse boundary off Whitemark, Flinders Island, 1991. (Note impact of jetty & creek mouth)

Abrupt *Heterozostera tasmanica* boundary and patchy beds, Marion Narrows, Blackman Bay, 1984

Patchy *Heterozostera tasmanica* and *Zostera muelleri* beds with gradual inshore boundary, Cloudy Lagoon, Bruny Island, 1984

Abrupt boundary of *Posidonia australis* bed and clear but irregular bounday of *Heterozostera tasmanica* in Tamar below Low Head, 1985

Stringy *Posidonia australis*, *Amphibolis antarctica* and *Heterozostera tasmanica* beds near Little Green Island in Adelaide Bay, Flinders Is. 1991

Abrupt to clear boundary of *Zostera muelleri* near entrance to Little Swanport, including oyster racks, east coast of Tasmania, 1985

The texture and density of coverage within the bed will also reflect external environmental factors, particularly where they are close to the species' threshold of tolerance. Thus, in communities where external factors become more dominant than internal ones, the internal and external boundaries become simpler, and their variety is reduced (Canny 1981). The external environmental factors that limit seagrass communities include depth, light attenuation, water energy, temperature and substratum (see Section 2.3). Abrupt boundaries occur where the environmental gradient of these is steep, and more diffuse boundaries where less so.

Strong currents or wave action prevent diffuse boundaries developing, and create a simplified sharper boundary between the bed and the point at which the external energy is too high. These boundaries are observed as a sharp demarcation of perhaps less than 1 m between the seagrass bed and seagrass absence. At the other end of this scale, the influence of a gradual environmental gradient may be observed as a decrease in the density of the seagrass bed reducing to zero. This may occur over a distance of tens, perhaps hundreds of metres, and represents a boundary zone. In this project the internal boundary of this zone has not been mapped. The position of its external boundary has been the central question.

Whereas sharp boundaries are readily perceived, diffuse boundaries are more of a problem, particularly on remotely sensed images, and are therefore difficult to map. Mapping errors for abrupt boundaries are limited to the inherent errors of the methodology adopted, such as position fixing, the scale of remotely sensed data, scanning, digitising or drawing errors, and the scale of the output. For diffuse boundaries, the difficulty in describing a line to indicate the extremity of a bed adds an additional error. It is therefore important that subjectivity is controlled by a clear set of criteria so that decisions on boundary positions are consistent and repeatable. This is necessary if the ongoing monitoring of change in a given boundary is to produce meaningful results.

Kelly (1980) describes four typical patterns of seagrass beds and the situations in which they are commonly found. These are:

(1) dense beds found in the lee of islands, shoals and reefs;

(2) beds which experience wave erosion and suffer blowouts which tend to enlarge and join together. These have a stringy appearance in aerial photographs;

(3) beds with edges that are diffuse and poorly defined. These are usually found in protected lagoons and estuaries, and are often extensive; and

(4) circular "patch" beds. These Kelly (1980) found occuring in sediment-filled depressions in hard substrates such as limestone.

Of these, 'stringy' beds and 'diffuse' beds found in sheltered sites pose problems for the mapper. Methods for classifying boundaries by shape and texture are used in other fields. For example, with reference to the boundaries between soil horizons, McDonald *et al.* (1990) gave scales to describe boundary distinctness and boundary shape. These can usefully be applied to other systems involving boundaries, including seagrass communities, and have here been adapted for this purpose (see Table 3.1).

Table 3.1

Classification system for seagrass bed boundary widths and shapes (adapted from McDonald *et al.*, 1990).

a. **Boundary distinctness**

	Boundary distinctness	Suggested seagrass boundary width
S	Sharp	< 1 m
A	Abrupt	1-5 m
C	Clear	5-10 m
G	Gradual	10-25 m
D	Diffuse	> 25 m

b. **Boundary shape**

S	Smooth	almost a plane surface
W	Wavy	undulations with depressions wider than they are deep
I	Irregular	undulations with depressions deeper than they are wide
T	Tongued	depressions considerably deeper than they are wide
B	Broken	discontinuous

Table 3.1 gives a terminology for boundaries of different widths in the field. Boundary widths could be expected to indicate environmental gradients of different steepness. Boundary shapes may similarly reflect environmental gradients, but also the growth patterns of different seagrass species. Although boundaries have not been classified in this study, such an approach provides an additional tool in monitoring change in future case studies.

A range of possible criteria could be adopted when determining the position of the boundary of a seagrass community, both in the field and from aerial photographs. Two examples are briefly discussed here:

(1) The outer limit of the root mat could be taken as the limit of the bed. Any gap between root mats from adjacent areas of leaf shoots therefore would therefore indicate a separate bed. This approach would be expensive in time and resources to adopt, and may require significant disturbance of the substratum. The difference between the rhizome boundary and that of the shoots may be insignificant considering other errors in the mapping system. Additionally, rhizomes may be present yet dead; therefore the presence of leaf shoots is a more reliable criterion for the presence of living seagrass.

(2) The mid point of the boundary zone is considered the boundary of the bed. This approach is often used in vegetation mapping where two communities merge. It is less useful in the case of seagrass mapping, because if any decline is occuring it is more likely to happen at the extremities of a bed, particularly the deeper boundary (H. Kirkman, pers. comm. 1992). A line drawn inside the extremes of a bed may thus fail to detect die-back in the outlying shoots in subsequent surveys.

Boundary criteria that have been found useful in this study include:

(1) For field sampling, a minimum level of shoot density is set as the boundary of the community, (e.g. less than 5% coverage, or shoots more than 0.5 m apart). All shoots outside this boundary would be regarded as individuals and not part of the community. In practice, this approach is adopted *de facto* when mapping from aerial photographs (see below), since, under a minimum level of shoot density for a given aerial photograph scale, seagrasses cannot be detected, particularly against a dark substratum.

(2) On aerial photographs, the limit of perceivable seagrass is taken as the boundary. The minimum shoot density thus becomes the minimum perceivable density. Unfortunately this is not a constant between sites, at different photograph scales, and for different photograph runs of the same site due to changing environmental and scale conditions.

(3) Where the seagrass becomes indiscernible from the water with increasing depth or turbidity the boundary is drawn at the last point that seagrasses can clearly be detected. This has many potential errors, and infers that the deeper boundaries will be very unreliable in the final maps. This can only be overcome with accurate ground-truthing and position fixing, which is obviously not possible with archival photography.

(4) where cover is 'patchy' or 'stringy' over an extensive area, the whole area is classified as a community and the density assessed accordingly.

(5) Where a boundary is irregular, tongued or broken, the closest fit is drawn. When small patches occur at a distance from the larger community they are grouped where the distances between them are less than the size of the patches, and drawn individually where that distance is greater. Density is then assessed accordingly.

These approaches have been adopted in this study when digitizing the seagrass bed boundaries from aerial photographs, and essentially mean that a line that most faithfully follows the furthest perceived extremity of the bed has been drawn. However, particular problems remain when dealing with irregular or patchy seagrass cover. In this study these problems became insurmountable when mapping Maria Island, leading to incomparable results between different time periods. Perhaps the underlying issue is that valuable results can be obtained provided any mapping errors are small in relation to the area of a bed and any changes observed (Fuller 1983). These errors and the limits of resolution of the maps must be explicitly stated (VIMS 1989).

3.3 Mapping definition & accuracy

The errors incurred in producing a map from a ground truthed aerial photograph accumulate chronologically through the process in the following order:

(1) the scale and distortions of the aerial photograph,

(2) the accuracy of defining and tracing the boundary,

(3) errors in keying the aerial photograph into the existing coverage in the database,

(4) the accuracy of following the traced boundary line when digitising,

(5) the resolution of the digitiser

(6) errors incurred through the approximations inherent in the computer hardware and software,

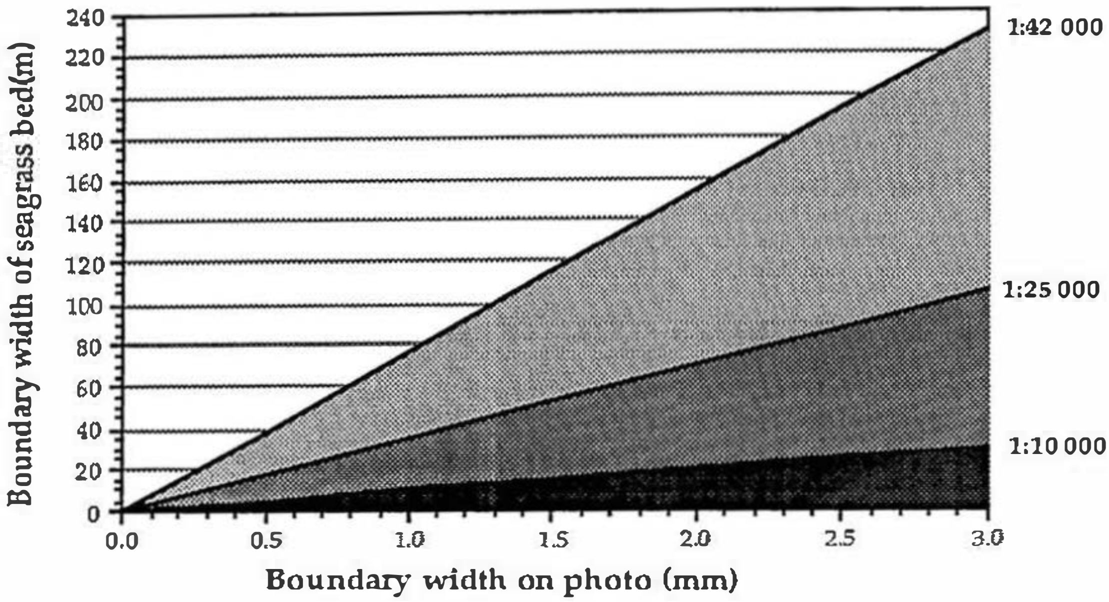
(7) the accuracy of the map plotter, and

(8) the scale and line thickness of the map.

Estimates of these errors are given in the methodology (Chapter 4). However, regardless of their accumulated value, the scale of the aerial photograph has an overiding impact on the resolution and usefulness of the final result. Figure 3.3 indicates the true size in the field of an object measured on an aerial photograph, such as the thickness of a line, or the width of a boundary zone.

Figure 3.3

Comparative boundary widths of seagrass beds and aerial photographs at different scales

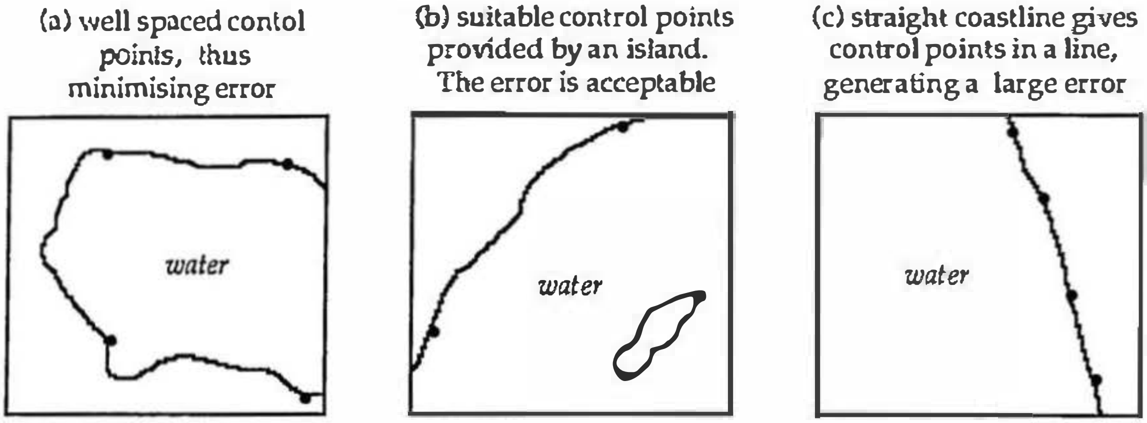


For example, Figure 3.3 shows that the width of a 'gradual/ diffuse' boundary 25 m wide in the field will appear 2.5 mm wide on a 1:10 000 scale aerial photograph, but only 1.0 mm wide on a 1:25 000 aerial photograph. At the scales of aerial photographic surveys flown in Tasmania since their inception in the late 1940s, boundaries that would be classified as 'sharp' or 'abrupt' in the field cannot normally be differentiated on aerial photographs. Further, where, for example, the thickness of a line drawn by a plotter on a map is 0.2 mm, this will represent 2 m at 1:10 000 scale, 5 m at 1:25 000 scale and 8.4 m at 1:42 000 scale.

A lack of control points is a problem in mapping coastal features. They are essential for keying a photograph into the database. In ARC/INFO they are referred to as "tics". Ideally four or more tics, whose precise coordinates are known, are chosen close to the corners of the photograph. On land, choosing tics is less difficult than on coastal images where the coastline may occupy only a small part of the scene. Further, precise features for use as tics are often absent on sandy or flat coasts, and where a shoreline varies with the state of the tide. Significant errors are thus introduced, and otherwise useful aerial photographs may have to be rejected (see Figure 3.4).

Figure 3.4

Diagram illustrating the problems of finding adequate control points (tics) for digitising from coastal aerial photographs



Other errors include:

(1) aerial photographs and maps are subject to paper shrinkage of 1-2% (VIMS 1989),

(2) calculations of area using a digitiser, where inaccuracies are introduced by edge effects (see Figure 3.2).

This discussion has highlighted many points at which inaccuracies may be incurred in the mapping process. In small scale intensive projects these can be kept to a very minor percentage of the mapped area. In a more geographically extensive project such as this, relying on available remotely sensed data, a lesser degree of accuracy is the cost for which the benefit is a broad picture of seagrass communities in the State.

Chapter 4
METHODS

"Large-scale observation and sampling of the marine environment presents the researcher with many problems not faced in comparable studies on land. The aquatic medium constrains data collection both in the field and by remote sensing"

(Kenchington 1990, p. 36).

4.1 Field data collection

During the course of this project 938 samples were recorded from nearly 150 areas of the Tasmanian coast. Sampling took place over the summer months of 1992, with some additional sampling in the spring of the same year, and the Huon River was sampled in early 1993. At each sample site a number of parameters were recorded (see Section 4.2), and entered into a GIS database.

4.1.1 Sample areas and zoning

From the distribution of the five major species described by Hughes and Davis (1989), five coastal regions, or zones, were defined, based on the patterns of the species present. These zones are:

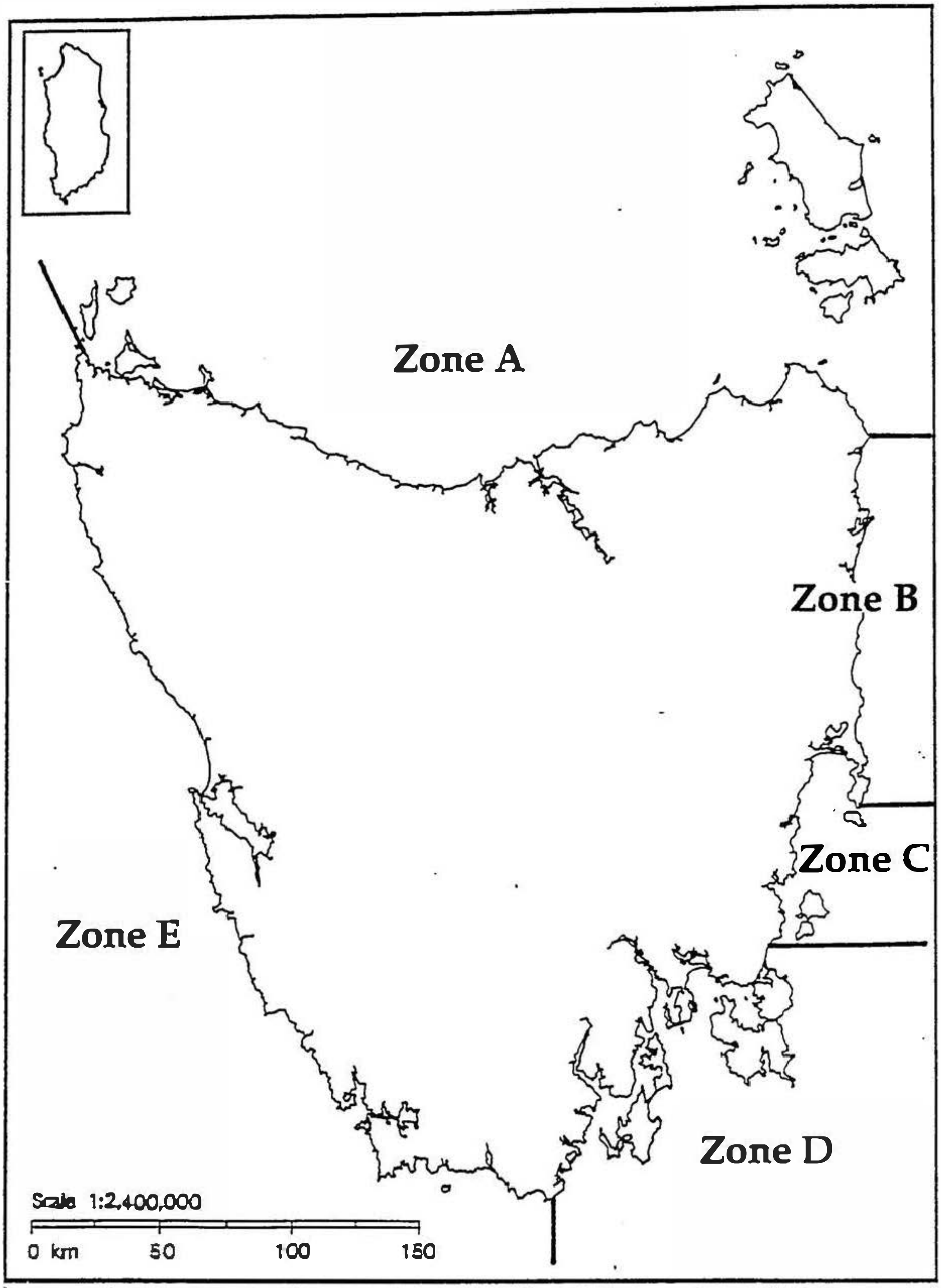
Zone A: all species present
Zone B: *Heterozostera tasmanica, Zostera muelleri*
Zone C: *Amphibolis antarctica, Halophila australis, H. tasmanica, Z. muelleri*
Zone D: *H. australis, H. tasmanica, Z. muelleri.*
Zone E: *H. tasmanica*

One outcome of this research has been to confirm or adjust these zones. In addition, within each zone the sample data enabled a description of the habitat range of each species in terms of coastal features, depth, and substratum. The zones are illustrated on Map 4.1, and sample sites indicated on Maps 4.2 to 4.5. Table 4.1 gives a complete list of sample areas, their reference numbers, and the coastal types they include.

4.1.2 Access

Access to coastal areas was by small craft. Many areas were visited by the researcher in a 3 m fibreglass dinghy, which required very calm conditions for safety. However, the size of this craft allowed easy access to shallow water bodies. Some areas were sampled using a 4 m aluminium dingy or a larger twin hulled craft provided by the Division of Sea Fisheries. This enabled more rapid coverage of the coastline in a wider range of weather conditions, although

Map 4.1:
Tasmania, location of zones A, B, C, D & E



Zone A	all species
Zone B	*Heterozostera tasmanica, Zostera muelleri*
Zone C	*Amphibolis antarctica, Halophila australis, H. tasmanica, Z. muelleri*
Zone D	*Halophila australis, Heterozostera tasmanica, Zostera muelleri*
Zone E	*Heterozostera tasmanica*

Table 4.1:
Coastal sample areas used in this study

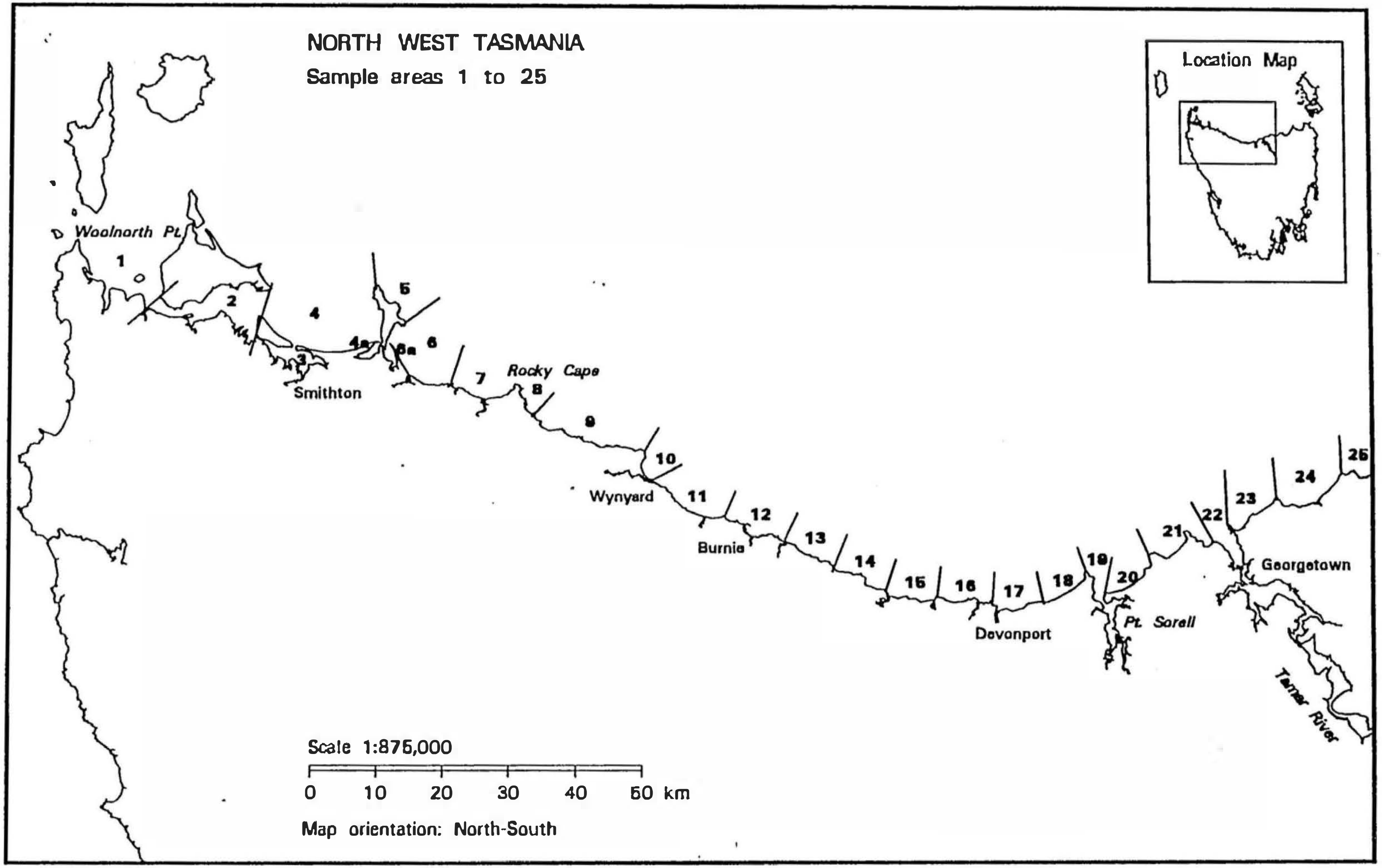
No	Area	Coast
Zone A		
1	Woolnorth Pt to Kangaroo Is	8/11
2	Kangaroo Is to Perkins Is	11
3	Duck Bay	7
4	Perkins Bay	9
4a	West Inlet	4
5	North Pt to Circular Head	10
6	Circular Head to Pt Latta	9
6a	East Inlet	4
7	Pt Latta to Rocky Cape	9
8	Rocky Cape to Sisters Is	10
9	Sisters Is to Table Cape	10
10	Table Cape to Wynyard	9
11	Wynyard to Cooee	10
12	Cooee to Heybride	9
13	Heybridge to Penguin	10
14	Penguin to Ulverstone	10
15	Ulverstone to Turners Beach	10
16	Turners Beach to Mersey Bluff	10
17	Mersey Bluff to Devonp't airp't	9
18	Devonport airp't to Port Sorell	10
19	Port Sorell	5
20	Griffiths Point to Badger Head	10
21	Badger Head to Friend Pt	10
22	Port Dalrymple	5
23	Low Head to Five Mile Bluff	10
24	Five Mile Bluff to Stony Head	9/10
25	Stony Head to Weymouth	10
26	Weym'th to W DoubleSandy Pt	10
27	W Double Sandy Pt to Bridport	8/9
28	Bridport to Croppies Pt	9/10
29	Croppies Pt toWaterhouse Pt	9/11
30	Waterhouse Pt toTomahawk Pt	9/10
31	Tomahawk Pt to Cape Portland	9
32	Cape Portland to L Mussel Roe	10
33	Little Mussel Roe Lagoon	4
34	Great Mussel Roe Bay	10
35	Mussel Roe Lagoon	4
36	C Naturaliste to Eddystone Pt	10
Zone A - Bass Strait Islands		
146	Parrys Bay (Whitemark)	9
147	Adelaide Bay (Lady Barron)	8
148	Cameron Inlet	4
149	North East River	4
150	Flinders Is (general)	-
151	Furneaux Group	-
152	Kent Group	-
Zone B		
37	Bay of Fires	10
38	Ansons Bay	4
39	Big Lagoon	2
40	Sloop Lagoon	2
41	Grants Lagoon	2
42	Binalong Bay to Grants Point	9
43	Georges Bay	4/5
44	Dianas Beach	10
45	Dianas Basin	2
46	Wrinklers Lagoon	8
47	Scamander Beach	10
48	Scamander River	3
49	Hendersons Lagoon	2
50	Four Mile Creek	6
51	Chain of Lagoons beach	10
52	Maclean Bay	10
53	Waubs Bay & Diamond Is	8
54	Friendly Beaches	10
55	Wineglass Bay	9
56	Schouten Is	8-10
Zone C		
57	Bryans Corner	8
58	Promise Bay	9
59	Coles Bay	8
60	Moulting Lagoon	4-6
61	Nine Mile Beach	9
62	Swansea to Webber Pt	9
63	Mayfield Bay	8
64	Buxton Pt to Little Swanport	9
65	Little Swanport	5
66	Pt Kelly to C Bougainville	9
67	Oakhampton Bay	8
68	Spring Bay	8
69	Prosser Bay	8
70	Mercury Passage (west)	9
71	Maria Is	8/11

Table 4.1 (continued)
Coastal sample areas used in this study

No	Area	Coast
Zone D		
72	Marion Bay	10
73	Blackman Bay	7
74	North Bay	9
75	Pirates Bay	8/9
76	Fortescue Bay	9
77	Port Arthur (Long Bay)	8
78	Port Arthur (Carnarvon Bay)	8
79	Wedge Bay (Parsons Bay)	8
80	Sloping Main & Sloping Is	9
81	Lime Bay & Monk Bay	8
82	Ironstone Pt to Deer Pt	8
83	Deer Pt to Sympathy Pt	8
84	Eaglehawk B & Little Norfolk B	8
85	Heather Pt to Chronicle Pt	8
86	Chronicle Pt to Dunbabbin Pt	8
87	Dunbabbin Pt to Fulham Pt	8
88	Fulham Pt to Primrose Pt	8
89	Primrose Pt to Tiger Head	9
90	Pitt Water (N of causeway)	4
91	" (S of causeway)	4
92	Sandy Pt to Cremorne	10
93	Pipe Clay Lagoon	7
94	Cape Deslacs to Cape Direction	10
95	Cape Direction to Gellibrand Pt	9
96	Ralphs Bay (Mortimer Bay)	7
97	Ralphs Bay (Rokeby)	7
98	River Derwent (above Tasman)	5
99	River Derwent (below Tasman)	5
100	North West Bay	8
101	Oyster Cove	8
102	Oyster Cove Pt to Deadmans Pt	8
103	Deadmans Pt to Birchs Pt	8
104	Birchs Pt to Three Hut Pt	9
105	Garden Is Bay & Randalls Bay	9
106	Port Cygnet	8
107	Huon R (below Brabazon Pt)	5
108	Huon R (above Brabazon Pt)	5
109	Port Esperance	8
110	Hastings Bay & Southport	5/8
111	Southport Lagoon	7
112	Recherche Bay	8
113	Dennes Pt to Woodcutters Pt	9
114	Shelter Cove & Barnes Bay	8
115	Apollo Bay	8
116	Snake Bay	9
117	Missionary Bay	8
118	Great Bay	8
119	Isthmus Bay	8
Zone D (continued)		
120	Alonnah & Satellite Is	9
121	Little Taylor Bay	8
122	Great Taylor Bay	8
123	Cloudy Bay	10
124	Cloudy Bay Lagoon	4
125	Adventure Bay	8
Zone E		
126	New River Lagoon	4
127	Kelly Basin	7
128	Bond Bay	9
129	Hannant Inlet	7
130	Bathurst Channel	5
131	Joe Page Bay	7
132	Horseshoe Bay	7
133	Bathurst Harbour	5
134	North Inlet	7
135	Moulters Inlet	7
136	Melaleuca Inlet/Lagoon	7
137	C St Vincent to Low Rocky Pt	10
138	Low Rocky Pt to Cape Sorell	10
139	Fraser Flats (Kelly Channel)	5
140	Maquarie Harbour	5
141	Trial Harbour	6
142	Granville Harbour	6
143	Pieman River	6
144	Arthur River	6

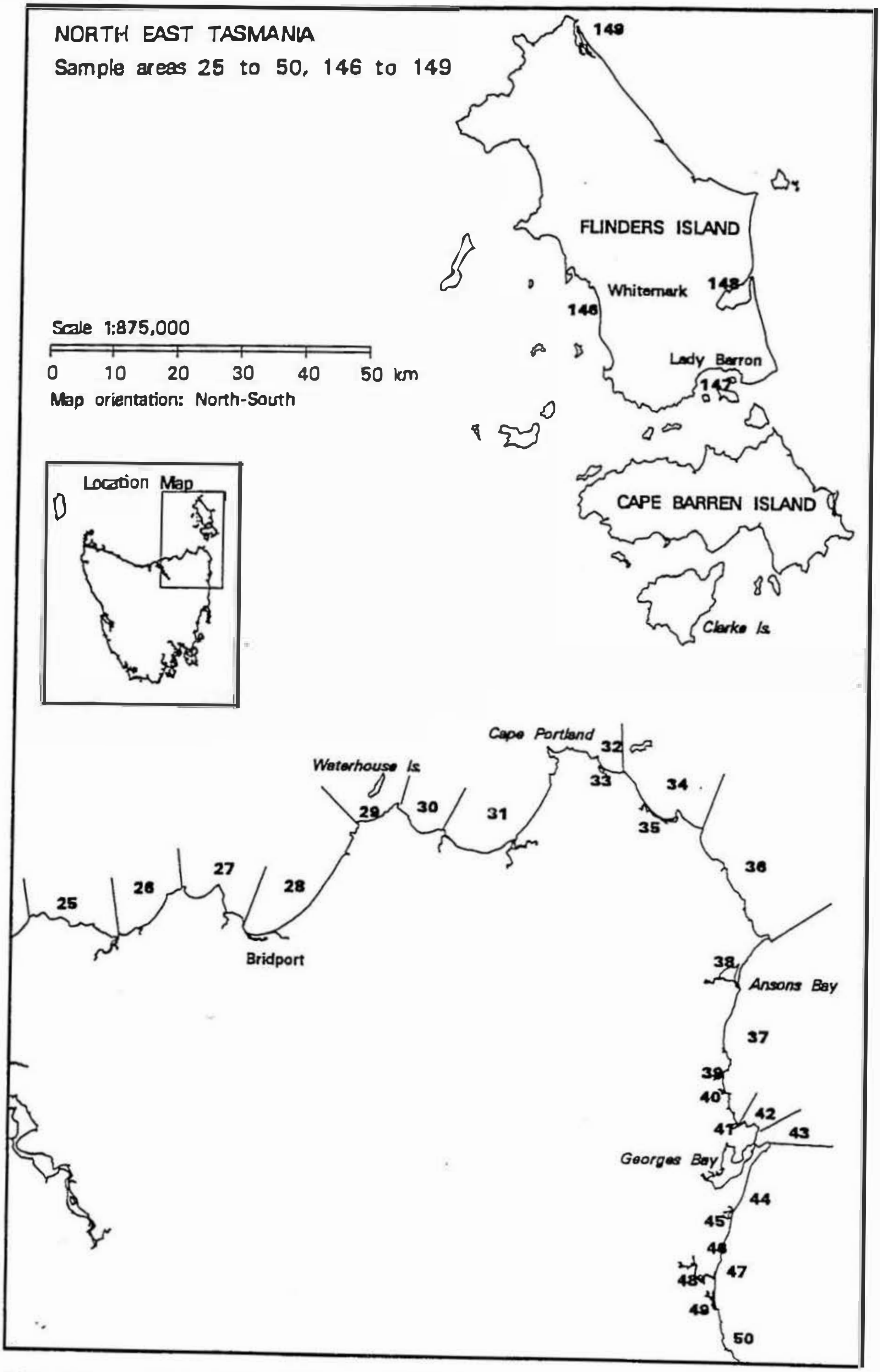
Coast types

1	coastal lakes
2	bar or beach dammed lagoons
3	bar or beach dammed rivers
4	open lagoons
5	estuaries
6	tidal rivers, creeks and tributaries
7	tidal arms
8	sheltered beaches & bays
9	semi-exposed beaches & bays
10	exposed beaches & bays
11	straits & channels

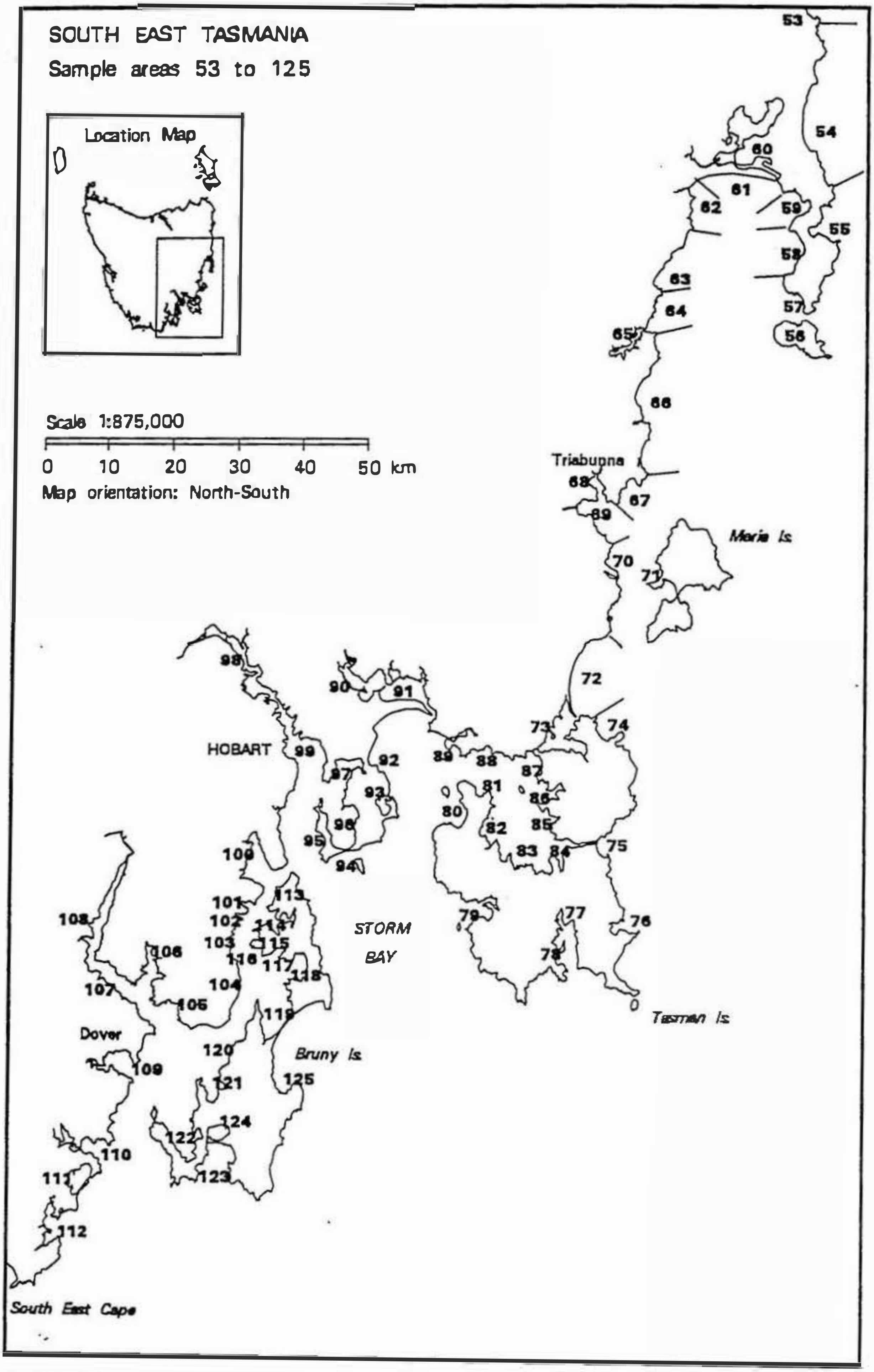


Map 4.2: North west region, coastal sample areas 1 to 25

Map 4.3:
North east region, coastal sample areas 25 to 50, 146 to 149

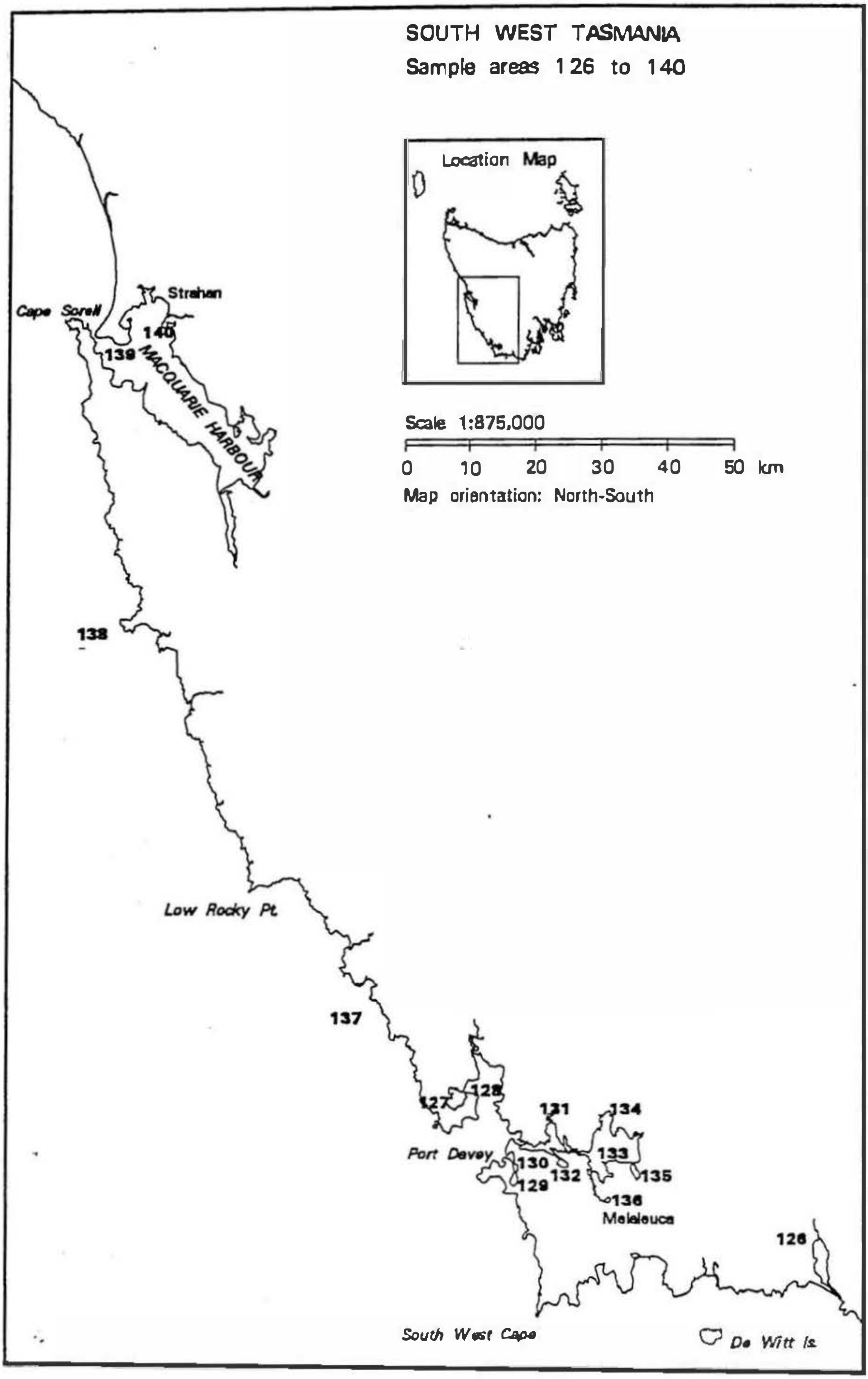


Map 4.4:
South east region, coastal sample areas 53 to 125



Map 4.5:

South west region, coastal sample areas 126 to 140



shallow water access was more difficult, and some intertidal areas could not be reached. The Department of Parks, Wildlife and Heritage provided water transport for sampling South West Tasmania, and local fishermen, oyster farmers and others provided water transport for Little Swanport, Blackman Bay, Flinders Island and Maria Island.

In areas of exposed coastline where seagrasses were unlikely to occur offshore, beaches were searched on foot for evidence of seagrass detritus (see section 4.5).

4.1.3 Constraints

The goal of sampling the entire Tasmnian coastline proved over-optimistic, and some areas of the north coast (areas 2, 4, 5, 9-14, 25, 30, 56), west coast (areas 137, 138, 139, 141, 143, 144),King Island and small sections of the east and south east (areas 66, 74, 75, 76, 111) were not visited. In some instances, reliable reports of the occurence of seagrasses in these areas were provided by local people or other researchers. In other cases the areas were very small, or considered marginal habitat for seagrasses and were passed over in favour of more significant sites due to time constraints.

The time available for sampling was restricted by the seasons, weather, and availability of craft. On numerous occasions planned trips failed to coincide with suitable weather conditions. This was a particular problem in sampling the north coast and Bass Strait, where long periods of north-easterly winds produced heavy seas and turbid conditions in the late summer of 1992. This coast was finally visited in spring 1992 in less than favourable weather. Sampling in this region was therefore influenced by turbidity, and access to potential seagrass habitat near reefs restricted.

4.2 Field data recording

To locate and ground truth seagrass beds in the sampling program, 1:25 000 maps and marine charts were used to identify coastal topography and bathymetry, and recent aerial photographs were used to target underwater objects such as reefs and vegetation beds.

Point sample and transect positions were fixed by compass and by intersecting line-of-sight reference to coastal features. Transects in shallow water were made from a boat using a bottom viewer and the bathymetry was measured. The depth boundaries between species were recorded, and the start and finish depths of the seagrasses measured. A number of attributes of point samples and transects were measured. All data was entered directly onto a map or chart, and a notebook.

A dredge was used to retrieve seagrass and sediment samples when turbidity or depth prevented visual sampling (see Plate 10 & Appendix II). This weighed only 5 kg and could be deployed by hand from any size of craft or from the shore. The dredge design was based on a double-sided anchor dredge described by Eleftheriou and Holme (1984). Large teeth (5 cm) were built into the leading edges of the dredge to cut through seagrass leaves into the root mat and substratum (see Plate 4.1). The dredge tended to bite immediately and lifted only a small sample. Damage to the seagrass bed was thus minimised.

In most cases the actual searching was considerably more extensive than the recorded samples indicate. In clear and calm conditions the presence or absence of seagrasses is clearly visible, and cruising at a low speed the benthos can be continually observed through a periscope. Thus, although point samples can be taken as being true of that particular location, in most cases they also indicate the homogeneous nature of the surrounding seagrass community.

The following attributes were recorded at sample sites:

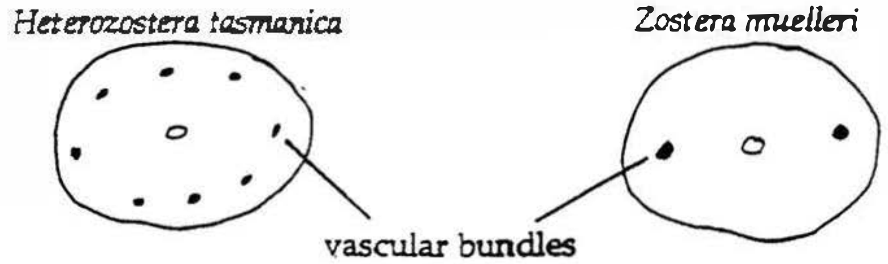
4.2.1 Seagrass presence or absence

Presence was recorded by listing the species found. When found growing in conjunction with seagrasses, macroalgae were recorded. The algal species were not individually identified. Macroalgal beds were recorded in some instances to avoid later uncertainty when digitising.

4.2.2 Species identification, collection and recording

Species were identified by sight, except in the case of *H. tasmanica* and *Z. muelleri*. These two species can be morphologically similar in some situations, but may be differentiated by sectioning of the rhizome to reveal the pattern of vascular bundles (Hughes & Davis 1989; Robertson 1984) (see Figures 1.3, 1.5 & 4.1). In situations where there was any doubt in the identification of these species, samples were collected for analysis in the laboratory.

Figure 4.1:
Heterozostera tasmanica and *Zostera muelleri*: rhizome internode cross-sections, indicating different arrangements of vascular bundles



4.2.3 Depth

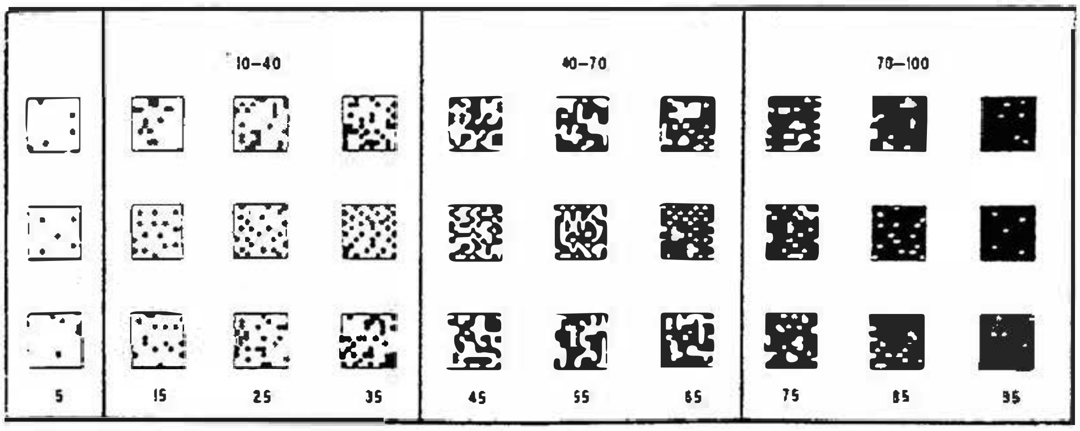
When possible, transects vertical to the shoreline were sampled, and the minimum and maximum depths of the seagrass beds were recorded. In some cases, i.e. turbid or rough conditions, only a point sample was taken and its depth recorded. Depths were measured to the nearest 0.5 m using a marked rope, or a depth sounder mounted on the vessel. Sample times and dates were recorded and depths adjusted to chart datum using Marine Board tables.

4.2.4 Density

A visual estimate of the percentage coverage of the substratum was made at each sample site, using a crown density scale described by Orth and Moore (1983) (see Figure 4.2). Four categories were used. This scale was similarly used when estimating the density of seagrass coverage on aerial photographs, and estimates from the field and from recent aerial photographs were compared to ensure consistency. The categories are:

(1) 1-10%
(2) 10-40%
(3) 40-75%
(4) 70-100%

Figure 4.2:
Crown density scale used to estimate the percent cover of seagrass beds (Orth & Moore 1983).



4.2.5 Algal epiphyte growth

The extent of growth of epiphytic algae was visually assessed. This included fine filamentous algae often found blanketing a seagrass bed. This is usually light green in colour, but occasionally dark green to black, and refered to by Shepherd *et al.* (1989, p. 352) as *"loose-lying accumulations of filamentous algae"*.

Alternatively, the leaf blades themselves may have supported an extensive growth of fine filamentous algae, giving them a 'bottlebrush' appearance. The extent of this algal growth over the seagrass bed was visually assessed using a 4 point scale (see Plates 7, 8, 9 & 10):

0 no algal epiphytes evident

1 algal epiphyte present throughout the bed but the seagrass leaves remaining predominantly free

2 the growth of epiphytes heavy and evident throughout the bed, but uncovered leaf blades or portions of leaf blades remain clearly visible, often protruding above the mass of epiphyte growth.

3 almost complete blanketing of the seagrass bed and substratum. In all situations the surface of the leaf blades appear completely covered.

Accumulations or mats of filamentous algae were sometimes found in locations where seagrasses might be expected to occur, and these were also recorded. These areas included shallow sheltered sections of bays and estuaries where aerial photographs indicated seagrass beds in the past.

4.2.6 Above-sediment shoot length

This parameter was recorded for *Amphibolis antarctica, Posidonia australis, Heterozostera tasmanica* and *Zostera muelleri* (estuarine form). These species had shoot lengths (vegetative shoots plus leaves) ranging from approximately 5 cm to 2 m, though usually less than 1 m. Samples were classified as less than or more than approximately 20 cm.

This parameter gives only a very simplified indication of the health of the seagrass bed. It is only of use in comparing the same bed with its state at different seasons, or at the same season for different years. It is of little value in any measurement of biomass or any other parameter, but is of qualitative interest.

4.2.7 Substratum type

Samples of substrata were not collected, although subjective field notes were made of the general character of the sediment. Where the seagrasses were sampled with a dredge, small quantities of the substratum were brought to the surface and could be examined. When only visual sampling was used a note was made of the surface appearance of the sediment. Again, this was at times verified by retrieving a sample by dredge.

The sediments were broadly described as coarse sand, fine sand, sandy mud and mud (cf: Last,1983). These categories approximately correspond to the Wentworth scale (Buchanan 1984; Brown & McLachlan 1990), and provide a simple sediment classification (Tait 1972).

4.3 Remotely sensed data

4.3.1 Aerial photograph selection

For this project three aerial photographic series were selected for each area, the first around 1950, the second around 1970, and the third between 1990 and the present day. As far as possible, photographic runs flown in late February and early March were selected to minimise errors due to seasonal fluctuations in biomass. This is also generally a period of stable weather and low rainfall giving relatively clear water condidions. Mapping only three periods of such a long time series runs the risk of failing to observe any natural long term cyclical fluctuations in seagrass distribution, but may indicate any large scale changes.

All aerial photograph identification details were recorded, and the scale noted (see Appendix I).

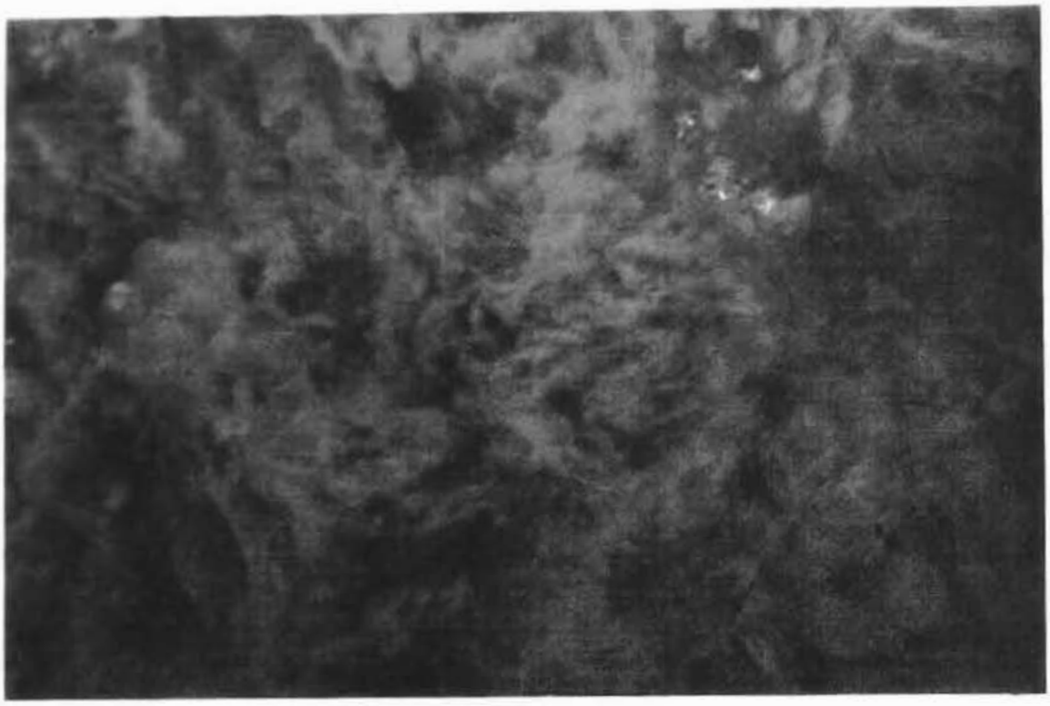
4.3.2 Digitising & data entry

The boundaries of seagrass beds on aerial photographs, previously identified through ground truthing, were first traced onto a clear acetate sheet using a 0.1 mm drafting pen. The boundary criteria described in Section 3.2 were used to identify the extremities of the seagrass beds. The photographs were registered into the database using control points selected jointly from the coastal outline and aerial photographs. Australian Map Grid (AMG) coordinates were used. The traced boundaries were then digitised by hand using a GTCO Digipad (TCG 2436L) and cursor. The resolution of the digitizing table is 0.05 mm. This data was entered into ARC/INFO in three separate layers corresponding to the chosen time periods (circa 1950, circa 1970 and recent (1990 to 1992)), using a coastal outline of Tasmania as a background coverage.

The sample site locations were similarly entered on a separate data layer, each having a unique identifier. The sample site attributes were entered into a database using Microsoft Excell, and subsequently transferred to ARC/INFO. These attributes were then associated with the corresponding sample sites and seagrass beds for subsequent analysis.

Once the digitising was complete, the polygons representing seagrass bed boundaries were edited, and vertices generalised to 1 m. The coverages were then cleaned to create a polygon topology and eliminate 'node errors' and 'dangles' using a fuzzy tolerance of 1 m. Sample sites were maintained unaltered in a separate coverage, but duplicated into the present day polygon coverage and

Plate 7:
Examples of algal epiphytes on seagrasses (a)



Heavy undifferentiated filamentous algal mat smothering the remnants of a *Zostera muelleri* bed, Cygnet, south east Tasmania

Dark algal epiphyte cover on shoots of *Heterozostera tasmanica*, Randalls Bay, south east Tasmania

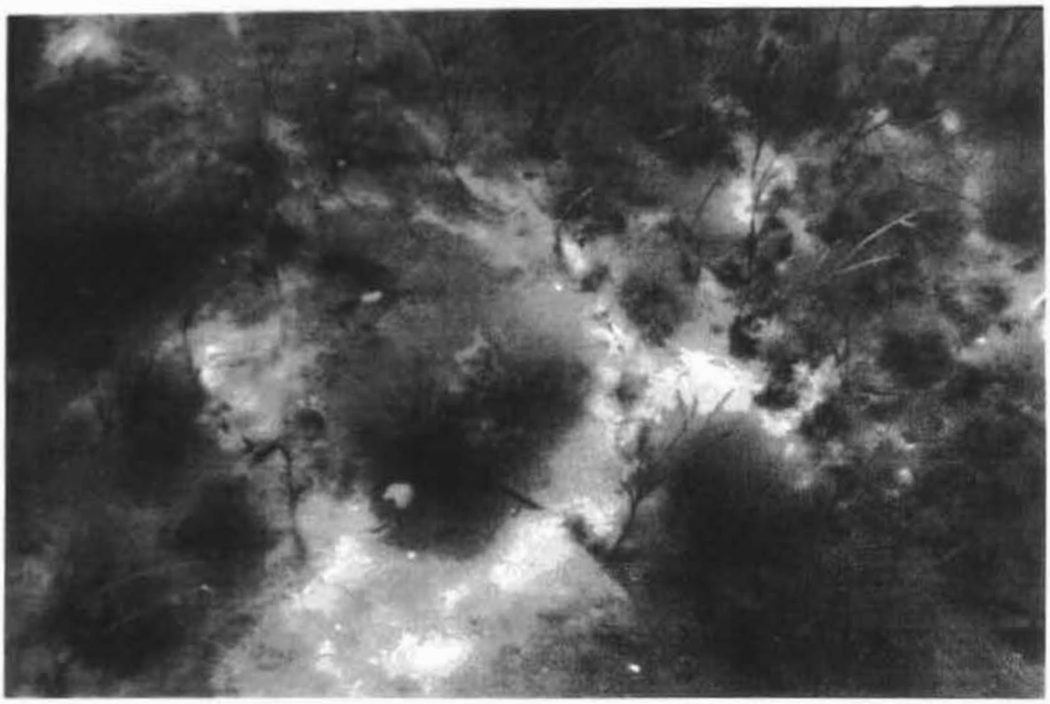
Plate 8:
Examples of algal epiphytes on seagrasses (b)

Algal epiphytes on *Heterozostera tasmanica*, Little Taylor Bay, south east Tasmania

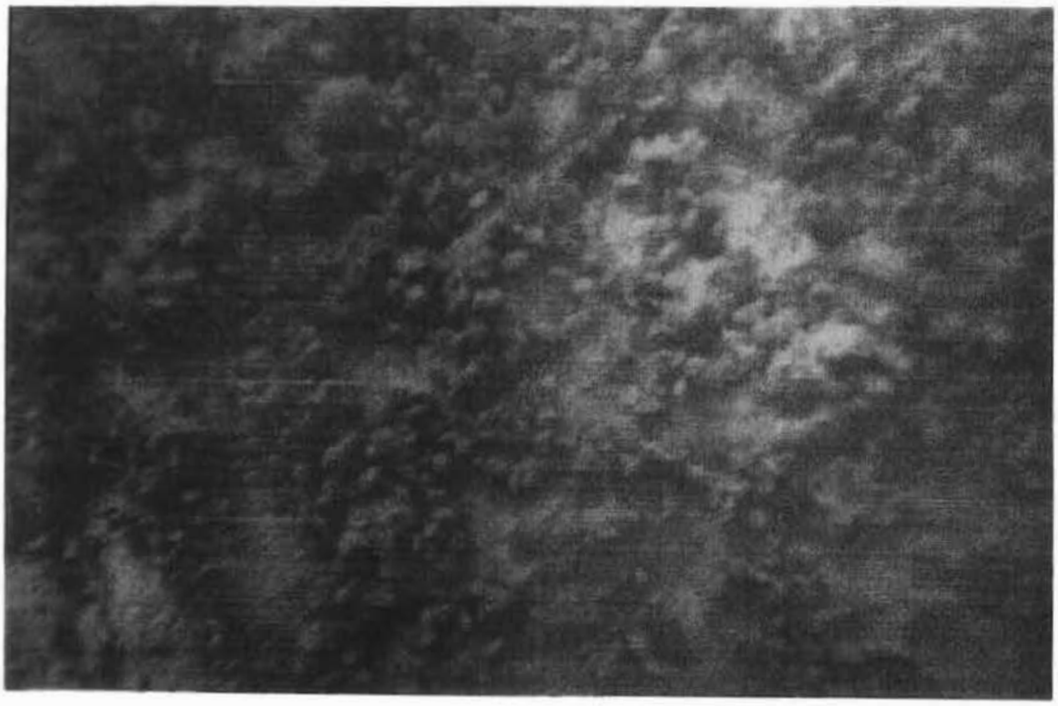
Algal epiphytes on *Heterozostera tasmanica*, North West Bay, south east Tasmania

Plate 9:

Examples of algal epiphytes on seagrasses (c)



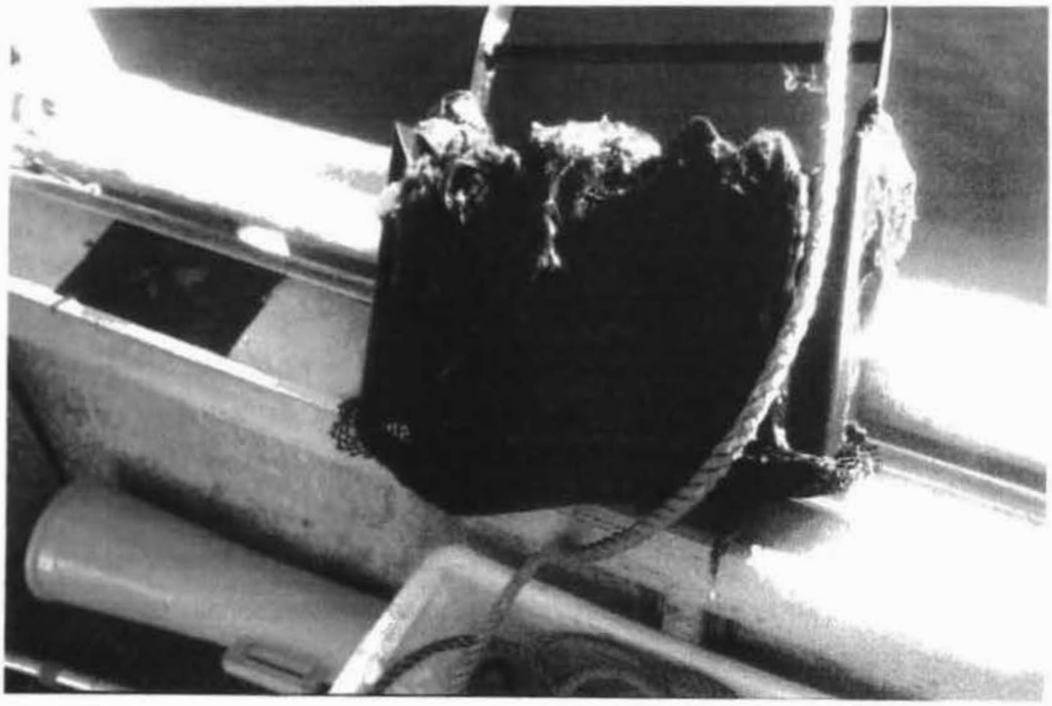
Algal epiphytes on *Heterozostera tasmanica,* North West Bay, south east Tasmania



Algal epiphytes and sediment on *Halophila australis,* North West Bay, south east Tasmania

Plate 10:

Algal epiphytes on *Posidonia australis*, and sample retrieved by dredge



Heavily epiphytised sample retrieved by dredge, Norfolk Bay, south east Tasmania

Heavy algal epiphyte covering on dead and dying *Posidonia* bed in Western Australia. (Photo courtesy of Western Fisheries Magazine, Fisheries Dept. of Western Australia) thinned to a one-to-one correspondence with polygons. Samples in this coverage outside polygons, or where duplicates existed within polygons, were eliminated.

4.3.2.1 Aerial photograph availability and quality

Although aerial photography is available for most parts of Tasmania since the mid to late 1940s, the following comments can be made from their use in mapping seagrasses in this project;

(1) most areas outside centres of human population are photographed infrequently, and very often these runs do not coincide with suitable weather or water conditions;

(2) aerial photography projects in recent years use a scale of 1:42 000 in areas outside human population centres. This is over four times smaller than the optimum scale recommended by other researchers (VIMS 1989). Aerial photography projects taken the 1950 and 1970 periods are generally a larger scale, leading to more accurate seagrass mapping; and

(3) due to points (1) and (2) above, the definition of seagrass bed boundaries was at times extremely poor, particularly for areas where the substratum is not sandy. Therefore the maps presented in chapters 5 and 6 cannot be taken as a precise picture of seagrass extent in a given area, even though they are stated to the nearest hectare. They do, however, offer the best guide to past and present seagrass coverage, and a basis for further research. The calculated changes in seagrass area can be taken as clear trends.

4.3.3 Analysis

The data was analysed to determine the following:

(1) profiles of individual species, their distribution in Tasmanian coastal waters, depth ranges, preferred coastal habitat types, and associations with other species;

(2) the area of seagrass beds in the present, and changes in area over time in selected case studies;

(3) the incidence of algal epiphyte loadings as a possible indicator of high nutrient loadings in the water body; and

(4) other impacts.

4.3.4 Map production

The mapped data and associated sample attributes exist as a digital database for future reference, analysis and additions. However, maps of selected coastal areas have been generated for inclusion in this thesis. Maps were formatted using ARCPLOT, and the map compositions transferred into postscript files for printing on an Apple laser printer. These have been produced at a scale of 1:50 000 for most areas, even though the resolution of the digitised data is greater than this. The coast in the Woolnorth area, Great Oyster Bay and Norfolk Bay has been printed at 1:120 000 as an overview, and some small areas have been presented at 1:25 000 scale.

The maps are of two types: those indicating the extent of seagrass beds and the position of sample sites (Chapter 5), and those indicating the changing boundaries of seagrass beds over time (Chapter 6).

Species distribution maps covering the whole State have been produced at a scale of 1:2 400 000, and the occurence of algal epiphyte loadings are mapped regionally at 1:875 000.

4.4 Associated data

4.4.1 Oral reports

At the start of the project articles were placed in Tasmanian regional newspapers and a fishing industry news magazine outlining the role of seagrasses, and requesting anyone with local knowledge of them to make contact with the researcher. Individual fishermen were also contacted. Leaflets were placed in diving shops, and individual divers were approached. In addition, researchers at the Division of Sea Fisheries, the University of Tasmania and the CSIRO were interviewed.

A number of divers, fishermen, oyster growers, researchers and members of the public volunteered information. This ranged from local knowledge of seagrass distribution and change covering many decades, to an awareness that seagrass detritus was no longer washing up on a local beach. In some areas, this information assisted the search for and location of seagrasses, and provided clues to possible causes of decline.

In a small number of sites, information from other sources has been included in the sample data. These areas include the more remote parts of the Furneaux Group, the Wynyard area, and Granville Harbour on the west coast.

4.5 Beach searching

Many beaches were searched for seagrasses washed up on the tide line. Seagrasses found in such searches are often indicative of the species present in an area, or of the absence of seagrasses when none can be found . There are many potential errors in this approach. Seagrass may be growing nearby but not be washed up on a beach, or it may be absent in the area but washed up on a beach due to prevailing wind and currents. Beach searching can not be considered a fully reliable test of the presence or absence of a particular species, however, it is a useful guide (H. Kirkman, pers. comm. 1992).

A five point scale was used in recording the findings of a beach search (see Figure 4.3). Searches were timed for 10 minutes. Where more than one species was present each was assessed separately.

The results of these searches were recorded in sample data, and the sites included in the GIS database. The location of these sites and the relative abundance of species is indicated on the distribution maps 5.1 to 5.6.

Figure 4.3

Scale of abundance of seagrass detritus on shorelines

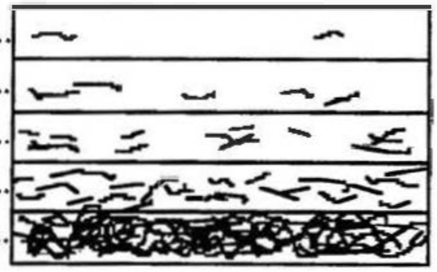
(1) a few leaves found with difficulty ....

(2) low occurence but easily found........................

(3) frequent patches and single leaves ....

(4) continuous presence along tideline ....

(5) large piles washed up along tideline...............



4.6 Data accuracy and reliability

4.6.1 Field sampling errors

The following variables influenced the accuracy and reliability of data from different sample areas:

(1) the availability of clear reference points in a coastal area for position fixing;

(2) the clarity of the water influencing the visibility of seagrass beds and other benthic features. This dictated whether sampling was purely visual, visual but using a dredge for confirmation of species, or blind, using the dredge alone. When turbidity was high and in tannin-stained water, sampling became more random and time consuming, and all assessments of boundaries and bed conditions depended on dredged samples; and

(3) the depth of seagrass beds in an area. Except in exceptionally clear water, sampling below 8 to 10 m has the same visibility problems as turbid water, and sampling is therefore by dredge alone, and thus blind.

The assumed accuracy of sample data is:

(1)	sample site location	± 100 m.
(2)	depth	±0.5 m
(3)	species identification	this is accurate for all species, except for the identification of *Heterozostera tasmanica* & *Zostera muelleri* in samples of beach detritus.
(4)	other sample parameters	these were measured in broad categories, and can be considered accurate within one category above and below that recorded.

In addition, because of limits on the extent of sampling in some areas, the maps in some areas may include some seagrass beds that were not ground truthed (e.g. Woolnorth to Robbins Island). It is however possible to identify species with a high degree of certainty by carefully comparing the density and texture of such areas with those of known beds.

4.6.2. Mapping errors

These are influenced by sample data accuracy described above, but additionally include errors introduced by the mapping proces itself.

ESRI (1991) suggest that the sources of error in producing a map are given by:

$$E = f(f) + f(l) + f(d) + f(a) + f(m) + f(p) + f(rms) + f(mp) + u$$

where, f = the transformation of the Earth's surface from sherical to planar geometry

l = accurate position fixing

c = cartographic interpretation (includes decisions on boundary placements, and interpretation of benthic features)

d = drafting error (recording of sample positions in the field)

a = analog to digital conversion (digitizing board calibration)

m = media stability (warping shrinking and other distortions in maps and aerial photographs)

p = digitizing processor error (the accuracy of cursor placement when digitizing)

rms = root mean square (accuracy in the registration of control points (tics) on aerial photographs when digitizing)

mp = machine precision (the rounding of coordinates by the computer when storing and transforming information)

u = additional unexplained sources of error

In reality the total of such errors makes only a very small addition to the position fixing, boundary tracing, aerial photography and digitising errors discussed earlier, since all the components of the formula are multiplied by the factor 'f'. This has a value of 1/298.25 (NMCA 1972).

Other factors such as pen size used in boundary tracing and map drawing, and variations in the scale, age and quality of aerial photographs also introduce errors.

Calculations of the area of seagrass beds are subject to all the potential sources of inaccuracy discussed above, and those quantified in Section 4.6.1.

Chapter 5
RESULTS - PRESENT SEAGRASS DISTRIBUTION IN TASMANIA

5.1 Species distribution

This chapter presents the results of the survey of seagrass distribution in those a eas sampled on a species basis, and on a regional basis. Data derived from the literature and oral accounts is included where it adds to the overall picture.

The sampling and mapping inaccuracies have previously been acknowledged. They must be borne in mind when examining the maps generated from the GIS database.

(Note: the numbers included in the text refer to sample areas. See Table 4.1, and Maps 4.2 to 4.5)

5.1.1 *Amphibolis antarctica*

Dis ribution: In Tasmanian waters this species has a range limited to zones A and C (see Map 5.1). In zone A this includes the length of the north coast, the Furneaux Group, and the Kent Group (Edgar 1984b). In zone C it is found on the central east coast from Great Oyster Bay to Green Bluff on Maria Island's west coast. This appears to be the southerly limit of its range in Australia. Within Great Oyster Bay it grows in small beds along the west coast of the Freycinet Peninsula to Coles Bay (59), and also south of Swansea (62) and in Mayfield Bay (63). Samples washed up on beaches in the Scamander area (44 & 47) were probably drift from the Furneaux Group, although local offshore islands require future investigation.

The total area of the species is not large, since it tends to occur in small dense patches, or as a fringe along beds of other species, particularly *Posidonia australis*. Good examples of this can be seen in the Tamar (22), and off the beach at Little Mussel Roe (32). Table 5.1 indicates those species with which *A. antarctica* was associated.

Coastal Types: *Amphibolis antarctica* was found in marine conditions in sheltered, semi-sheltered and exposed bays, straits and channels (see Figure 5.1). It was also common in the Tamar Estuary (22). It was not found in any rivers or lagoons.

Depth: The species was generally found in a depth range of 2.5 to 5.5 m, al hough it grows to at least 9 m in the Furneaux Group (J. Mason, pers. comm.). In those areas sampled, it was often in sites with higher water energy than other species. Thus *A. antarctica* was shallower than *P. australis* at Little Mussel

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Depth: The species was generally found in a depth range of 2.5 to 5.5 m, although it grows to at least 9 m in the Furneaux Group (J. Mason, pers. comm.). In those areas sampled, it was often in sites with higher water energy than other species. Thus *A. antarctica* was shallower than *P. australis* at Little Mussel

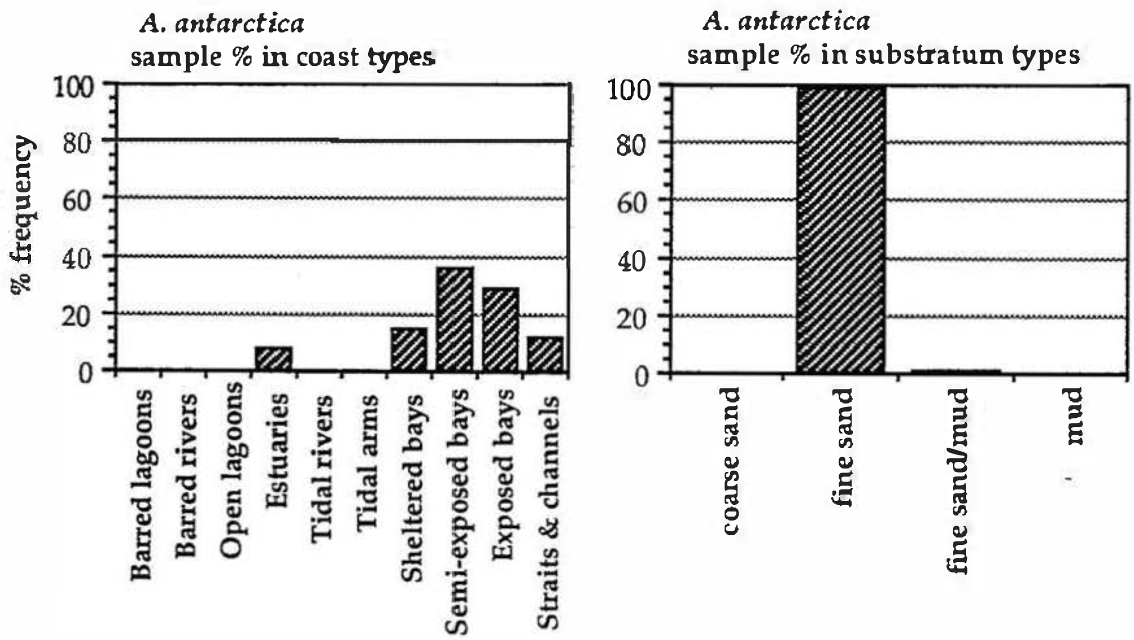
Roe beach where it formed a band closer to the surf line, and deeper than *P. australis* in the Tamar where it fringed *P. australis* beds along the edge of the main channel, tolerating the stong tidal currents.

Table 5.1:
Summary of *Amphibolis antarctica* species associations in samples

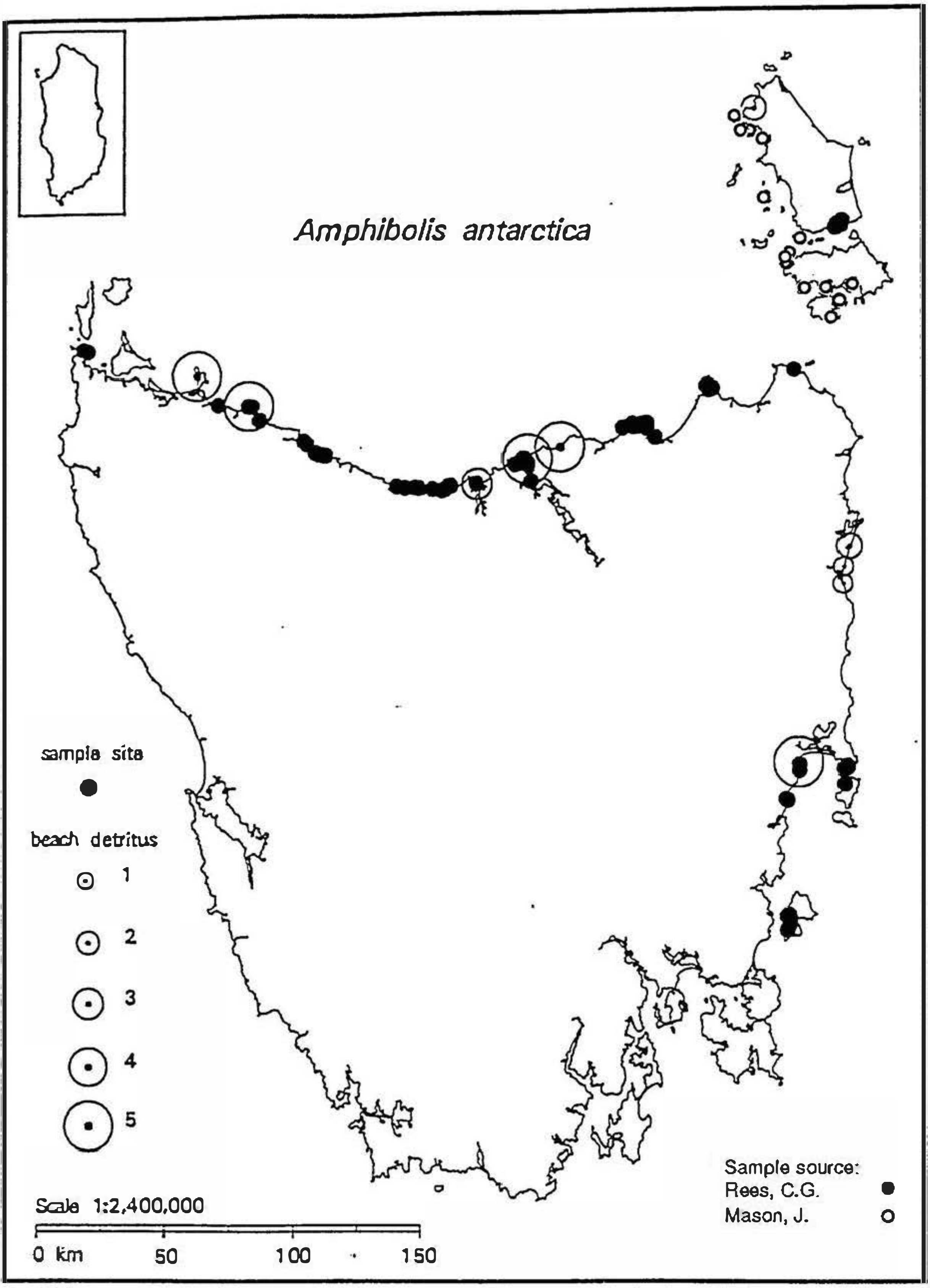
Associated species	Numbers of samples	Area mapped (ha)
Amphibolis antarctica only	64	150
with *H. tasmanica*	8	4
with *P. australis*	9	91
with *H. tasmanica* & *P. australis*	2	186
with *H. australis, H. tasmanica* & *P. australis*	1	not mapped
Totals	84	**431**

Substratum: With one exception (in the Tamar), *A. antarctica* only occurred only on fine sandy substrata (see Figure 5.1).

Figure 5.1:
Amphibolis antarctica distribution in coastal and substratum types



Map 5.1:
Amphibolis antarctica distribution



Total mapped area = approx. 431 ha, including 318 ha in community with other species.
Mean substratum cover in ***Amphibolis antarctica*** beds = 70-100%
Total live samples = 84 from 938, of which 20 included other species.
Beach detritus samples = 10 (2x1, 2x2, 1x3, 5x5).
Coastal types = 5, 8, 9, 11.
Maximum depth = 8 m.
Substratum types = fine sand, fine sand/mud, mud

5.1.2 *Halophila australis*

Distribution: This species was generally found in sheltered sites at shallow depths, and often associated with *Heterozostera tasmanica*. It was sampled in zones A, C and D. It is particularly common in the Norfolk Bay and D'Entrecasteaux regions. *H. australis* was otherwise only seen in Coles Bay (59), the Tamar (22) near Redbill Point, and off Lady Barron (147). However, it is also found in deeper areas among the islands of the Furneaux and Kent Groups.

Edgar (1984b) recorded *H. australis* growing between 25 and 35 m in sand patches on an exposed steep rocky substratum at South-Eastern Point, Erith Island, and J. Mason (pers. comm.) has found it growing to 17 m in Franklin Sound and other areas around Flinders Island. Sites at these depths were out of the range of techniques available in this study.

The delicate leaves of the plant make it difficult to recognise when dry in beach detritus. The lack of beach sightings may thus not reliably indicate its absence from an area.

Table5.2:

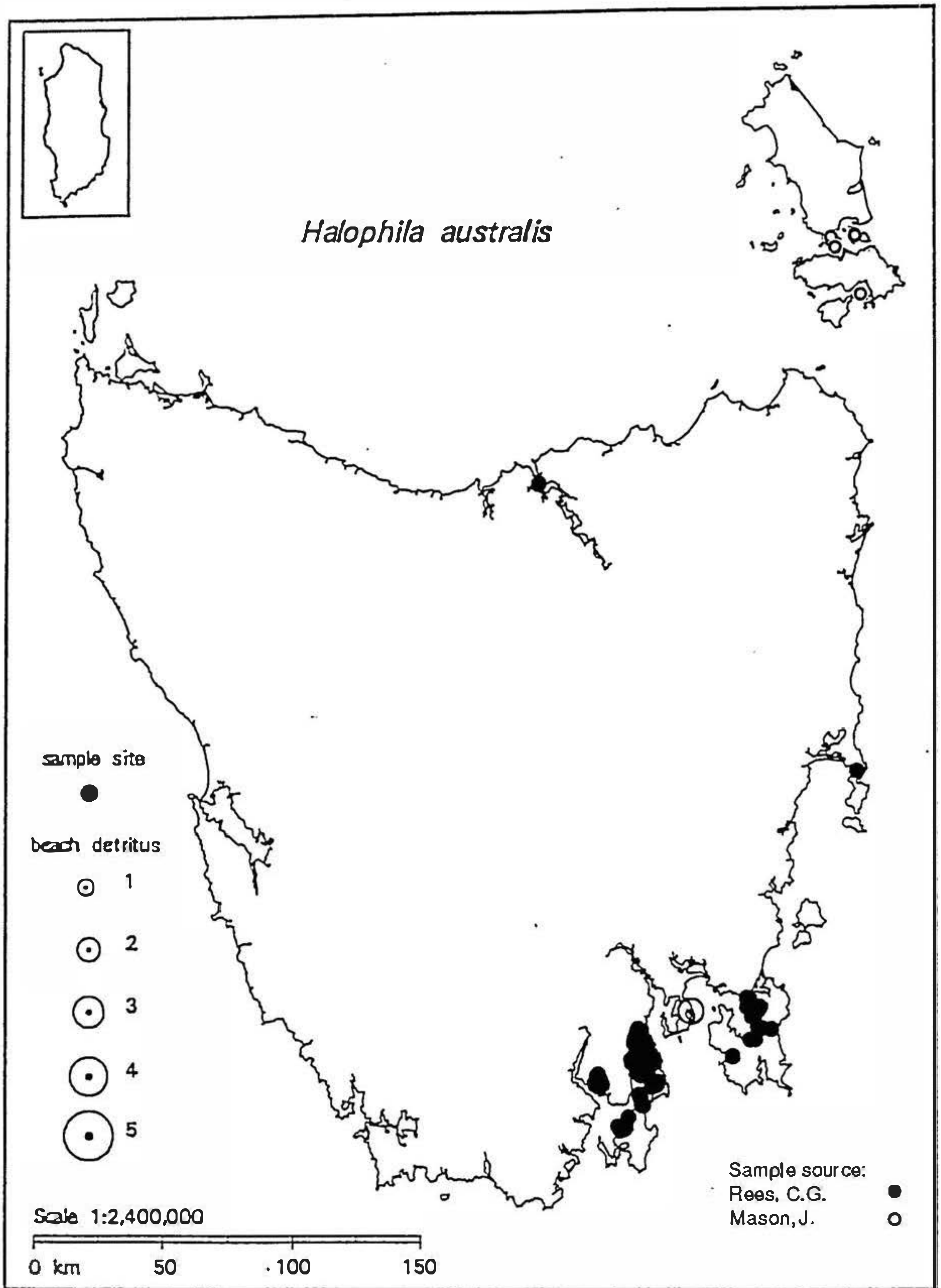
Summary of *Halophila australis* species associations in samples

Associated species	Numbers of samples	Area mapped (ha)
Halophila australis only	85	259
with *H. tasmanica*	62	953
with *Z. muelleri*	1	not mapped
with *A. antarctica, H. tasmanica P. australis*	1	not mapped
Totals	**149**	**1 212**

Depth: Most samples were found between 1.5 to 7 m, but in clear oceanic water it has been recorded up to 35 m (see above). It was most commonly associated with *Heterozostera tasmanica* in the south east, but usually had a deeper range than this species in those sites, appearing at 2.5 to 3 m and growing in mixed beds to 3.5 to 4 m. Such situations can be found in North West Bay (100), Barnes Bay (114) and other parts of the D'Entrecasteaux and Norfolk Bay regions.

Substratum: this species favours fine sandy sediments, although in parts of the D'Entrecasteaux region it was found growing in mud (see Figure 5.2).

Map 5.2:
Halophila australis distribution

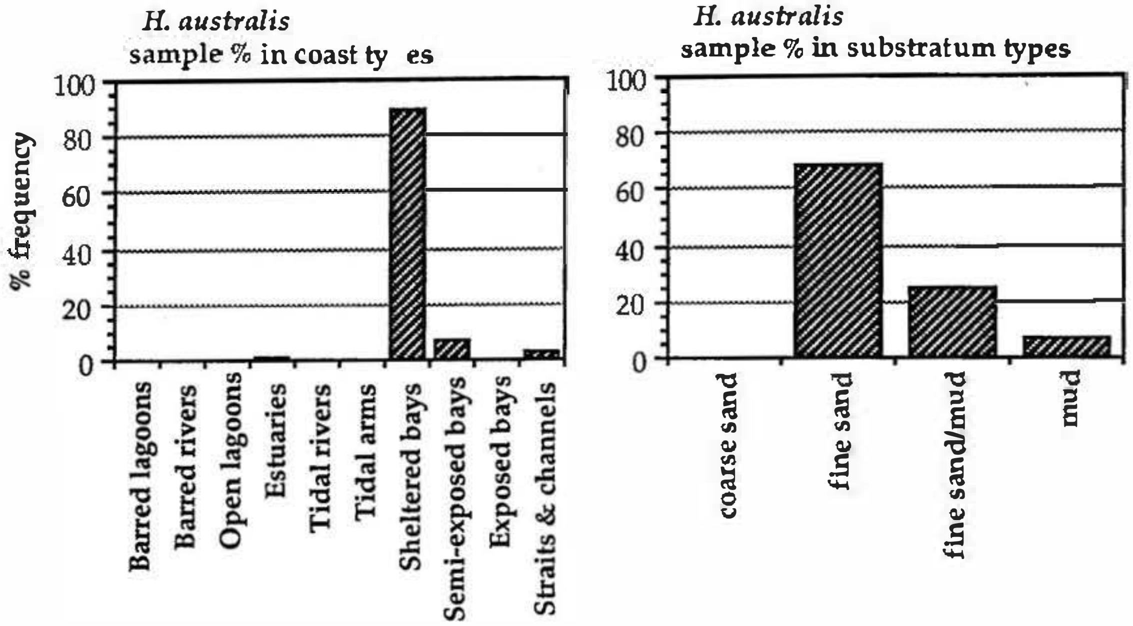


Total mapped area = approx. 1212 ha, including 953 ha in community with other species.
Mean substratum cover in ***Halophila australis*** beds = 40-70%
Total live samples = 149 from 937, of which 63 included other species.
Beach detritus samples = 1 (1x2).
Coastal types = 5, 8, 9, 11.
Maximum depth = 8 m.
Substratum types = fine sand, fine sand/mud, mud

Coastal Types: *Halophila australis* favours very sheltered bays, but will tolerate semi-sheltered conditions, and deeper sites below the impact of wave action and strong currents.

Figure 5.2:

Halophila australis distribution in coastal and substratum types



5.1.3 *Heterozostera tasmanica*

Distribution: *Heterozostera tasmanica* is found in all five zones in both estuarine and marine environments. The species probably occurs in many sites not sampled, since small beds of as little as a few square metres can be found in patches of sand in the shelter of reefs.

The majority of samples occured in the south east, including those associated with *Halophila australis*. The large areas of *H. tasmanica* with *Posidonia australis* were found in area 1 in the north west, and areas 146 and 147 off Flinders Island. In the Bathurst Harbour/Port Davey area in the south west, it was found with *Zostera muelleri sensu stricto* .

Coastal Types: *Heterozostera tasmanica* was found in all types of coastal formation except closed and semi-closed drainage systems (Table 5.3). Sample evidence suggests that there are clear limitations on its tolerance to low salinity, preferring marine conditions.

Depth: This survey recorded the species to only 10 m depth due to sampling limitations. In turbid, or tannin stained areas, it is confined to a narrower depth range. It was not found above the low water mark. It tolerates tidal currents in the channels of estuaries and lagoons, and in sheltered bays may form a well defined boundary beyond the effect of direct wave action (Norfolk Bay, 81 to

87). The depth range in association with *Halophila australis* has been discussed earlier. With *Posidonia australis, H. tasmanica* was found growing in small patches in blowouts, or as a fringe on the edge of channels or closer to wave action (see Plate 3).

Table 5.3:

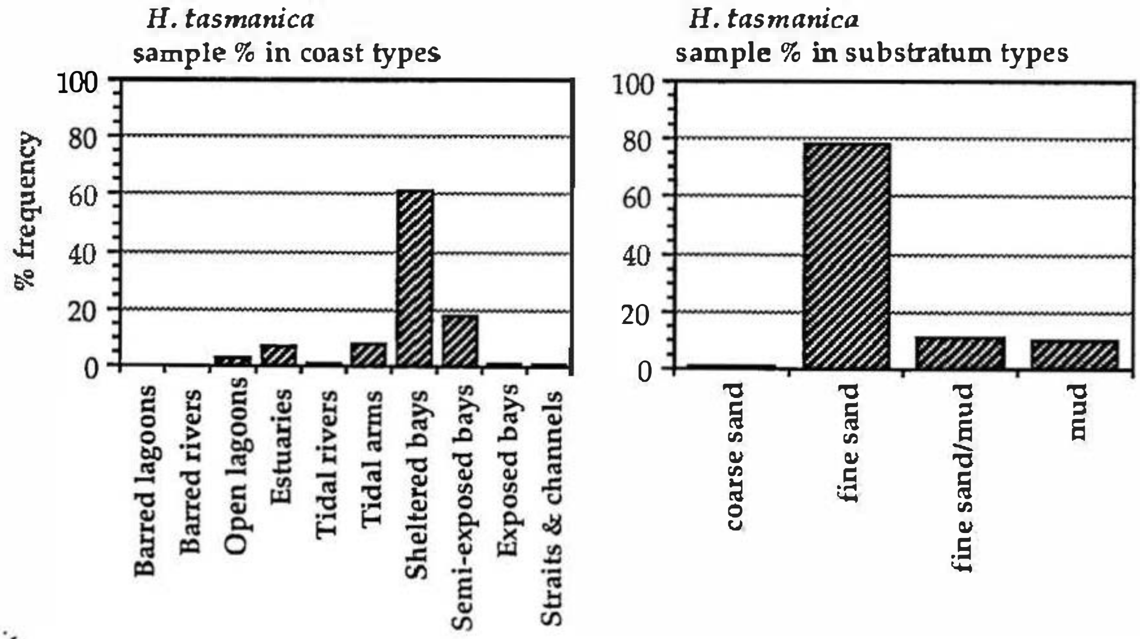
Summary of *H. tasmanica* species associations in samples

Associated species	Numbers of samples	Area mapped (ha)
Heterozostera tasmanica only	277	5 607
with *A. antarctica*	8	4
with *H. australis*	62	953
with *P. australis*	7	1 431
with *Z. muelleri*	2	1
with *Z. muelleri sensu stricto*	7	not mapped
with *A. antarctica* & *P. australis*	2	186
with *A. antarctica, H. australis* & *P. australis*	1	not mapped
Totals	**366**	**8 182 ha**

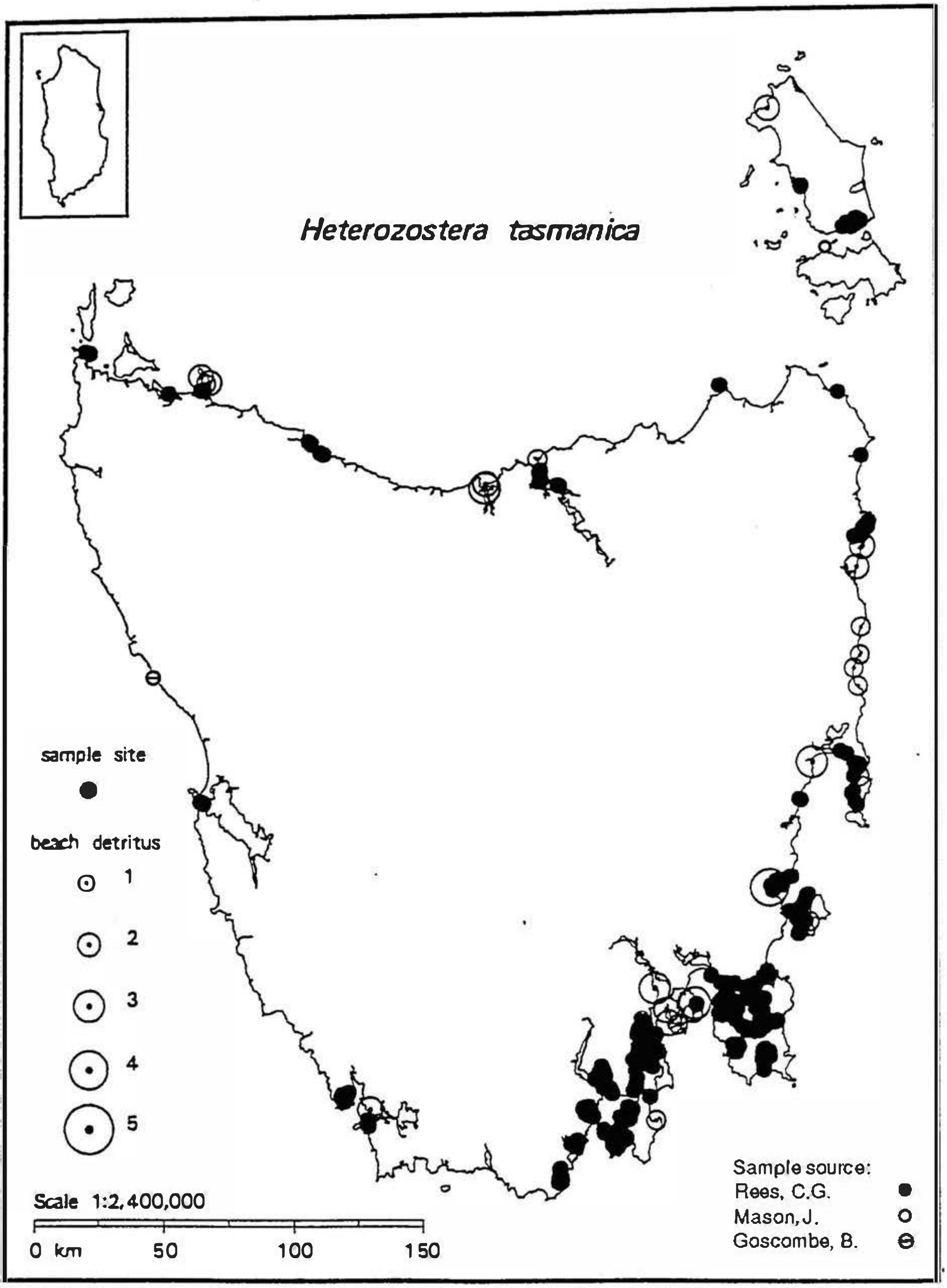
Substratum: *H. tasmanica* was found in all substratum classes used in this survey, from black heavy muds to coarse sands (Figure 5.3). Fine sandy substrata appear to support the densest and largest beds.

Figure 5.3:

Heterozostera tasmanica distribution in coastal and substratum types



Map 5.3:
Heterozostera tasmanica distribution



Total mapped area = approx. 8182 ha, including 2575 ha in community with other species
Mean substratum cover in ***Heterozostera tasmanica*** beds = 40-70%
Total live samples = 366 from 938, of which 41 included other species
Beach detritus samples = 26 (12x1, 9x2, 4x3, 1x4)
Coastal types =4, 5, 6, 7, 8, 9, 10, 11.
Maximum depth = 10 m
Substratum types = coarse sand, fine sand, fine sand/mud, mud

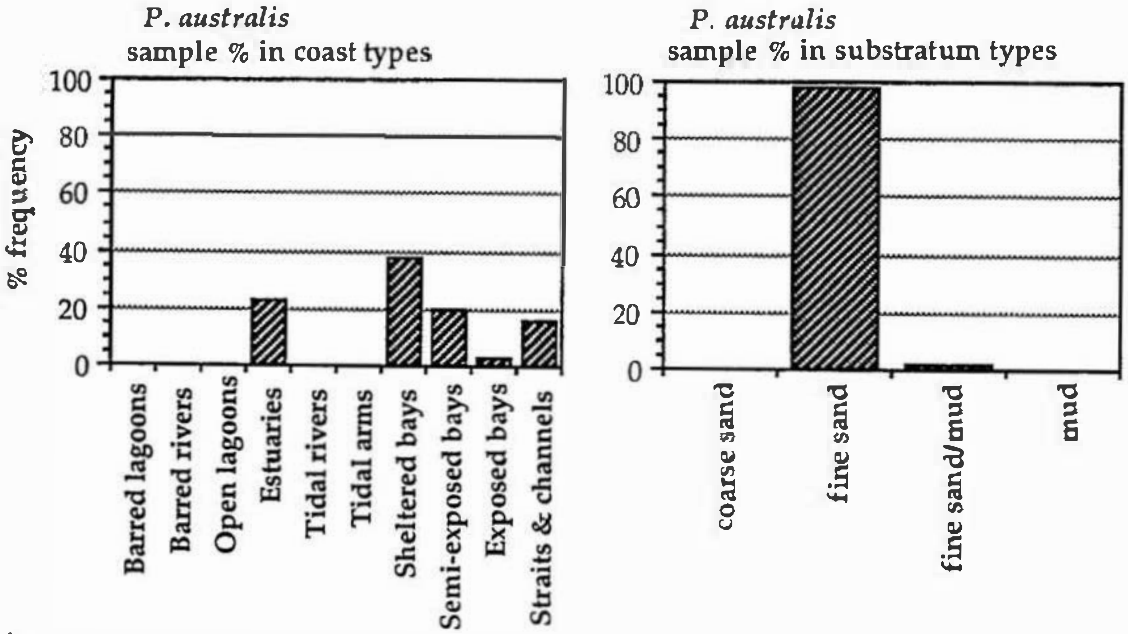
5.1.4 *Posidonia australis*

Distribution: In terms of area, this was the most abundant species, even though it is limited to zone A along the north coast of Tasmania and the islands in the east of Bass Strait. Over 108 km2 of seagrass beds were mapped in which *Posidonia australis* was the sole or dominant species (see Table 5.4). This is certainly short of its true extent in the State. This area includes only Woolnorth (1), the Tamar Estuary (22), Parrys Bay (146) and Adelaide Bay (147). The species is also found in the Kent Group, where Edgar (1984b) recorded *P. australis* at 6 m in sand on a sheltered site at Garden Cove, Deal Island, and in Murray Pass from shallow depths to 20 m.

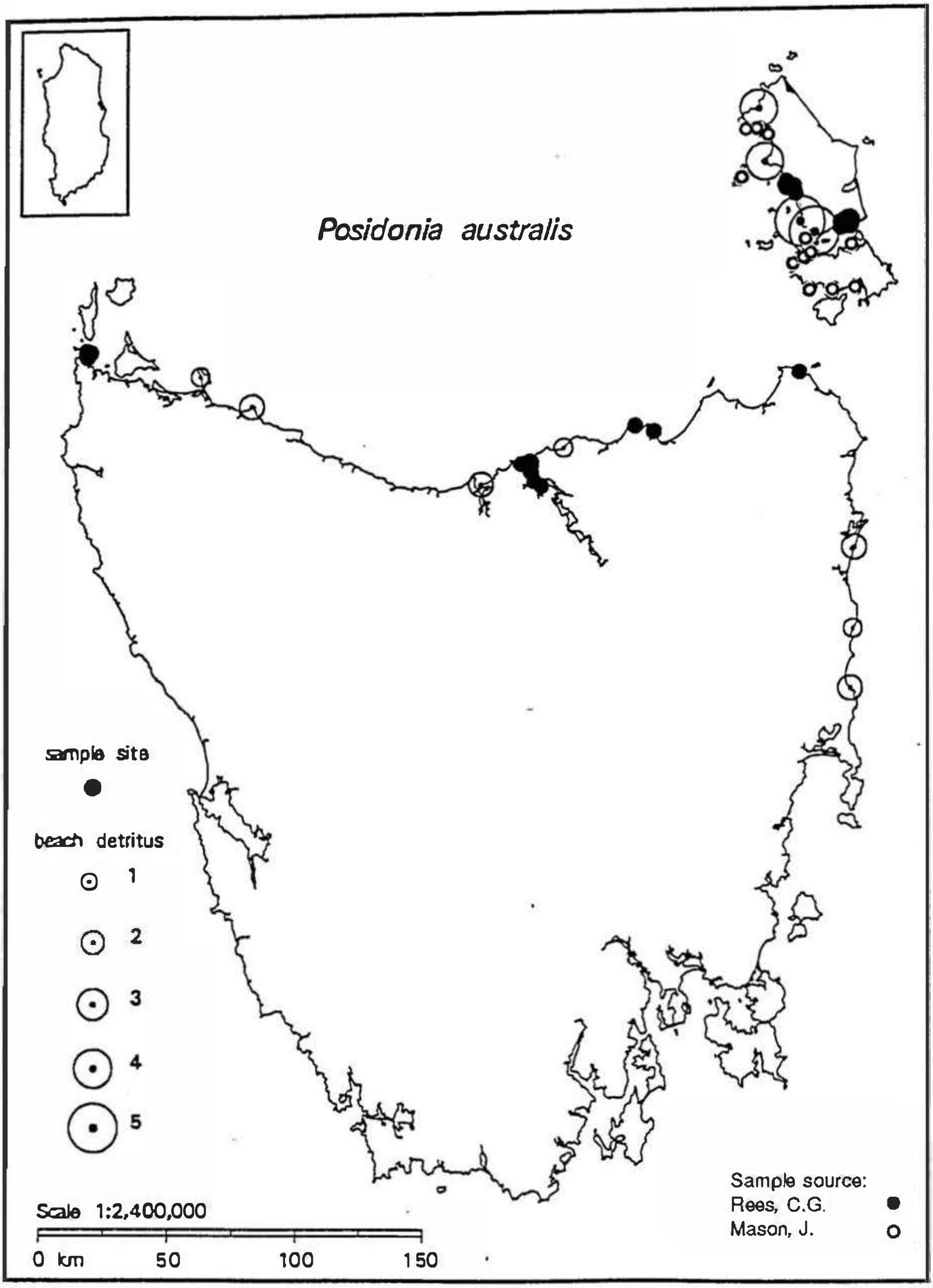
Table 5.4:
Summary of *P. australis* species associations in samples

Associated species	Numbers of samples	Area mapped (ha)
Posidonia australis only	45	9 085
with *A. antarctica*	9	91
with *H. tasmanica*	7	1 431
with *A. antarctica* & *H. tasmanica*	3	186
Totals	**64**	**10 849 ha**

Figure 5.4:
Posidonia australis distribution in coastal and substratum types



Map 5.4:
Posidonia australis distribution



Total mapped area = approx. 10,849 ha, including 1764 ha in community with other species
Mean substratum cover in ***Posidonia australis*** beds = 70-100%
Total live samples = 64 from 938, of which 41 included other species.
Beach detritus samples = 11 (3x1, 4x2, 0x3, 2x4, 2x5).
Coastal types = 5, 8, 9, 10, 11.
Maximum depth = 9 m.
Substratum types = fine sand, rarely fine sand/mud

Coastal Types: *P. australis* favours shallow sandy subtidal flats in sheltered to semi-sheltered bays, estuaries and channels (Figure 5.4). It also occurs off gently sloping sheltered to semi exposed beaches along sections of the north coast and Flinders Island, usually with a belt of *Amphibolis antarctica* or *Heterozostera tasmanica* protecting the shallower, higher energy edge of the bed.

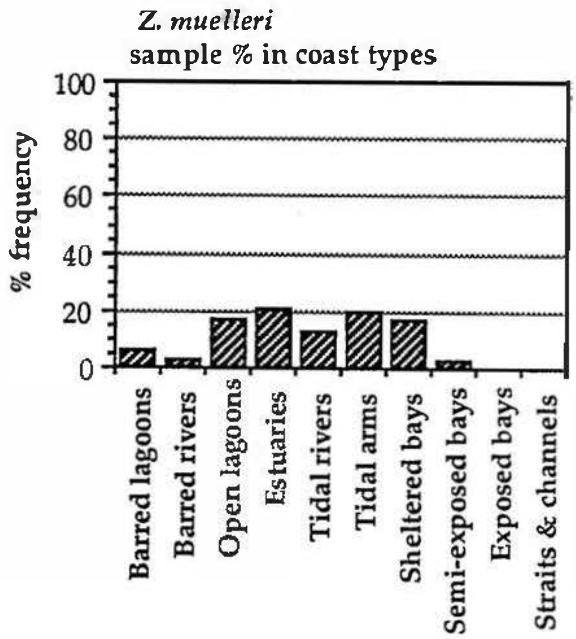
Depth: Although reported at considerable depths in the Kent group (see above), the deepest sample found in this survey was at 9 m, and the majority of beds were from 2 to 5 m in the habitat types described above.

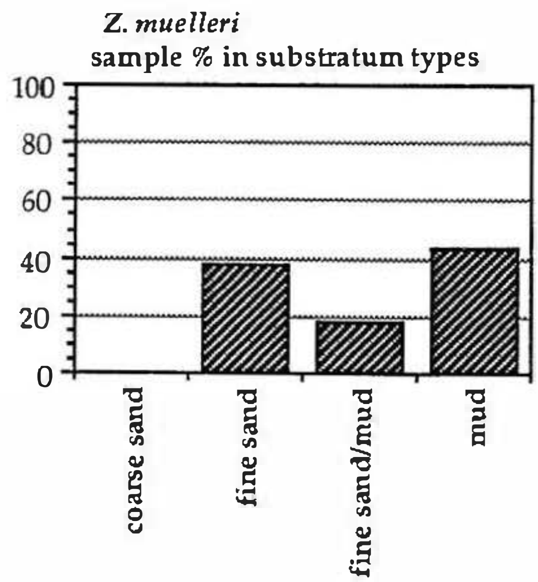
Substratum: *P. australis* occurred almost exclusively in fine sandy substrata (Figure 5.4), although it was growing in siltier sediments off Beauty Point in the Tamar (122).

5.1.5 *Zostera muelleri* and *Z. muelleri sensu stricto*

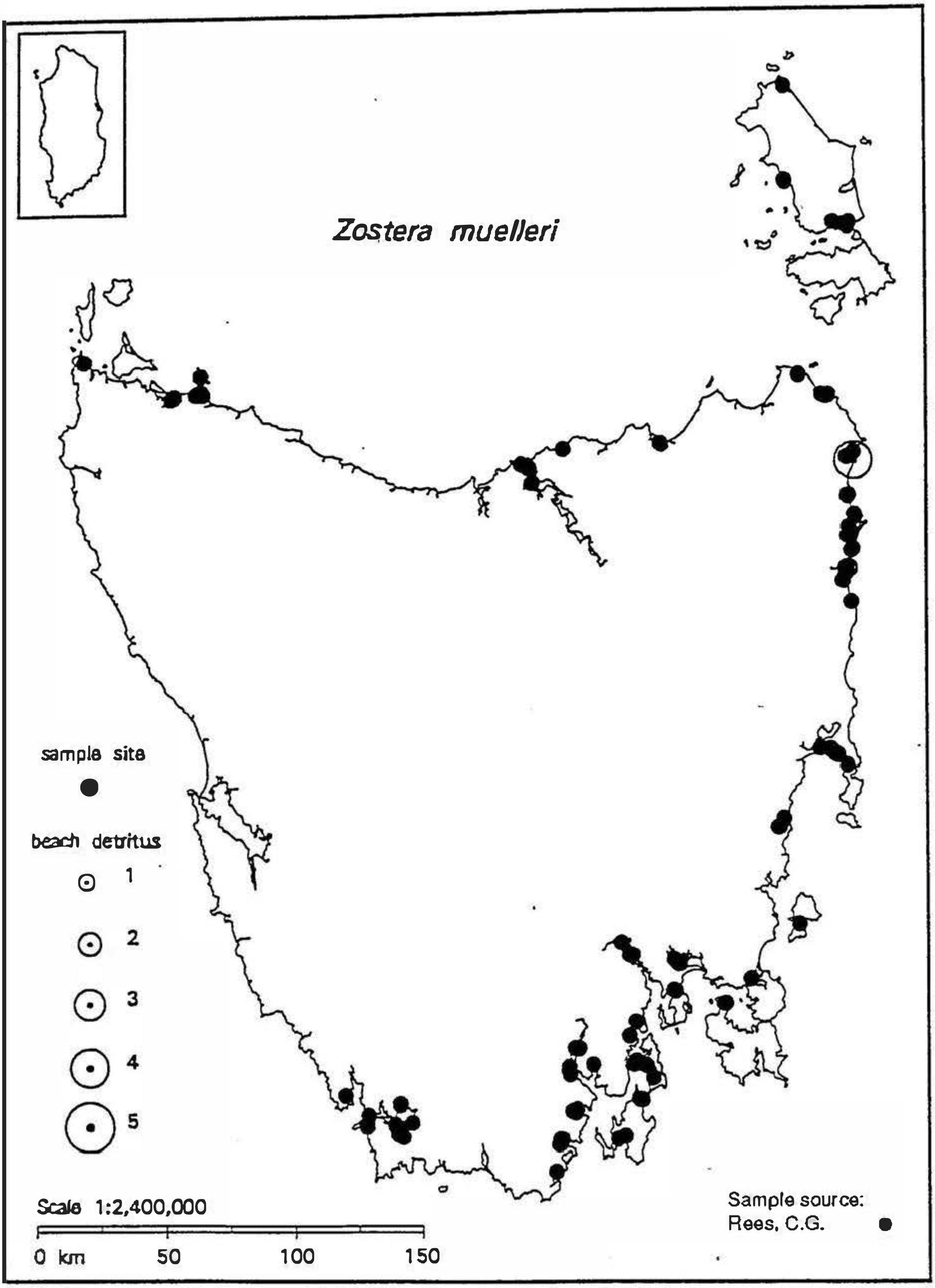
Distribution: This species was found throughout the State on sheltered intertidal flats, and permanently submerged in many lagoons and upper estuarine areas. It is therefore tolerant of a wide salinity range, from limnetic to hyperhaline, and a wide temperature range. Both forms of *Z. muelleri* were sampled, although *Z. muelleri sensu stricto* was only found in any abundance in the Port Davey/Bathurst Harbour area. The range of the species is greater than that described by Hughes and Davis (1989), who did not indicate its presence in zone E. Both varieties generally occured in monospecific beds, or bands (see Table5.5).

Figure 5.5:
Zostera muelleri coast type and substratum habitat preferences



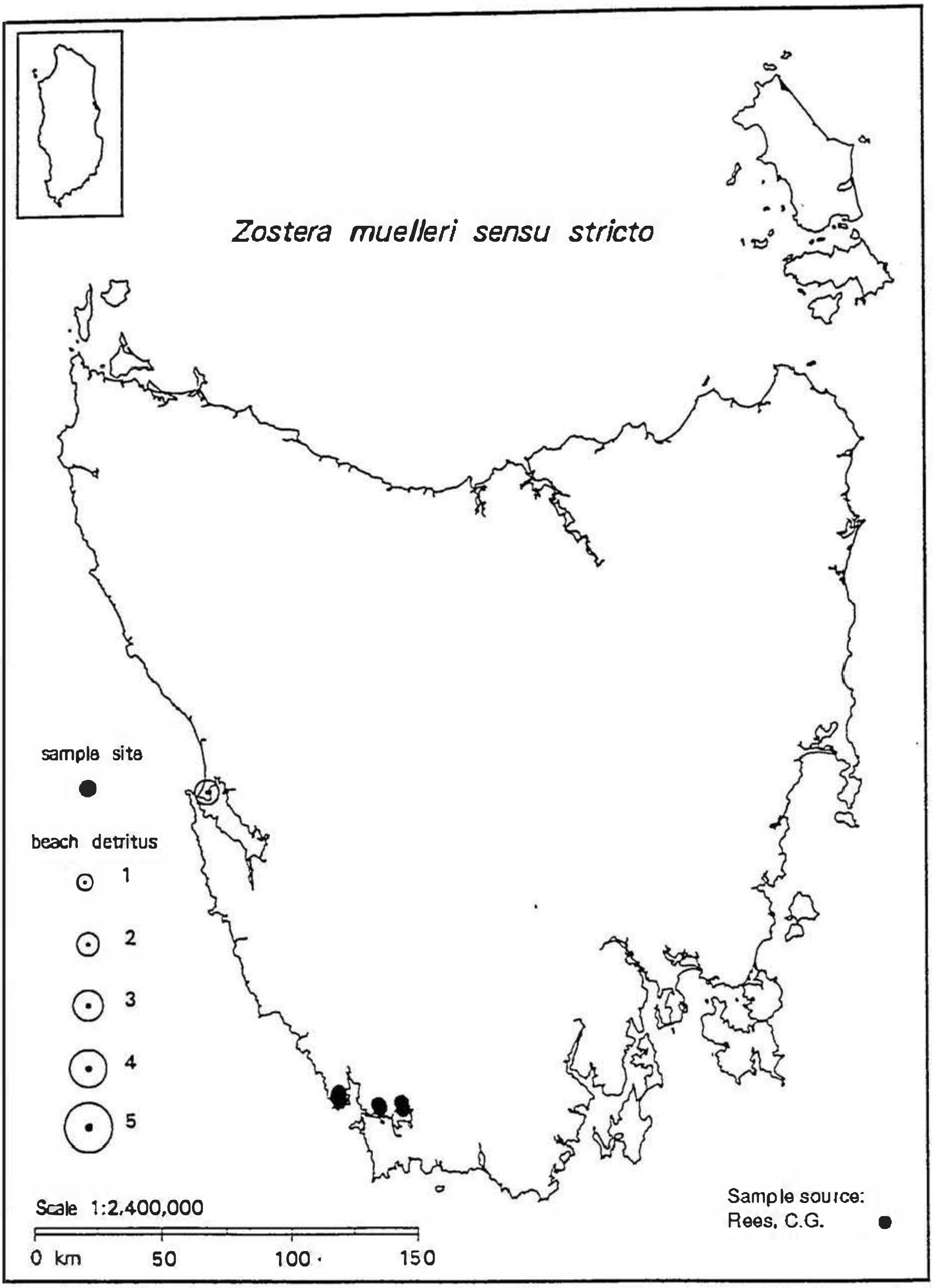


Map 5.5:
Zostera muelleri distribution



Total mapped area = approx. 4004 ha. including 57.3 ha in community with other species.
Mean substratum cover in ***Zostera muelleri*** beds = 40-70%
Total live samples = 120 from 938, of which 7 included other species.
Beach detritus samples = 2 (1x1, 1x4).
Coastal types = 4, 5, 6, 7, 8, 9.
Maximum depth = 2.5 m.
Substratum types = fine sand, fine sand/mud, mud

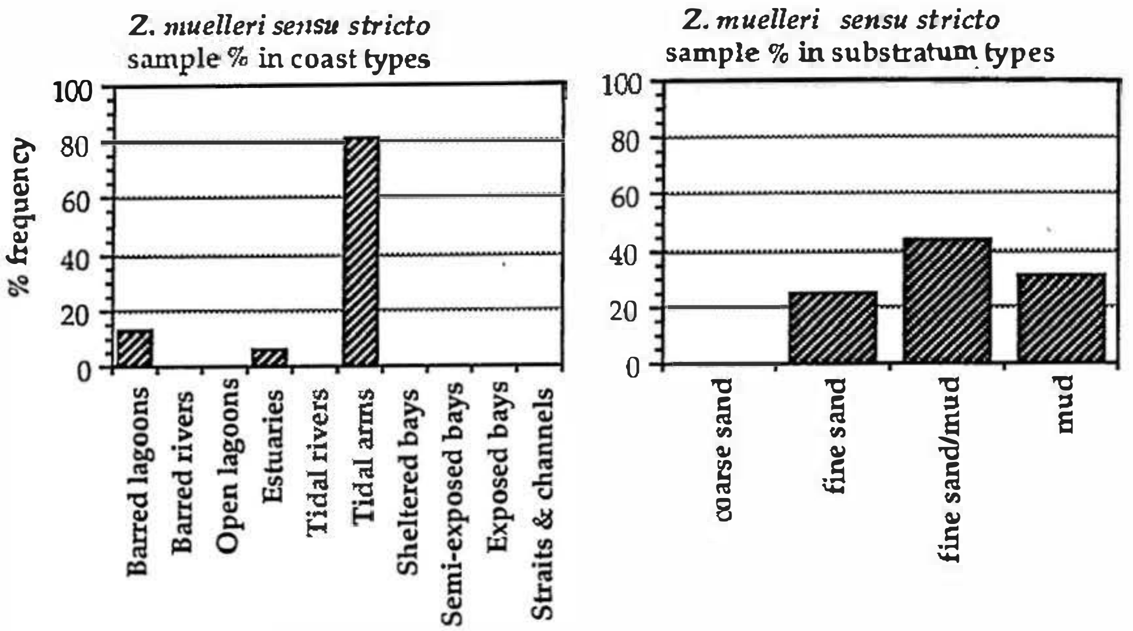
Map 5.6:
Zostera muelleri sensu stricto distribution



No ***Z. muelleri sensu stricto*** beds mapped
Mean substratum cover in sampled beds = 70-100%
Total live samples = 16 from 938, of which 7 included other species.
Beach detritus samples = 2 (2x2).
Coastal types = 2, 5, 7.
Maximum depth = 2 m.
Substratum types = fine sand, fine sand/mud, mud

Figure 5.6:

Zostera muelleri sensu stricto distribution in coastal and substratum types



Coastal Types: The broader-leaved estuarine form, *Zostera muelleri*, occured in semi-closed drainage systems (types 2 & 3), open drainage systems (types 4, 5, 6 & 7), and sheltered and semi-exposed beaches and bays (types 8 & 9) (see Figure 5.5). However, in semi-exposed beach/bay systems it favours very sheltered sites, and its inclusion in this category may be misleading. *Zostera muelleri sensu stricto* was mostly confined to the tannin stained limnetic shallows in tidal arms off Bathurst Channel (130) and Harbour (133), and Kelly Basin (127) (see Map 5.6).

Table 5.5:

Summary of *Z. muelleri* species associations in samples

Associated species	Numbers of samples	Area mapped (ha)
with *H. australis*	1	not mapped
with *H. tasmanica*	2	1
with *P. australis*	2	56
with *Z. muelleri sensu stricto*	2	not mapped
Totals	**120**	**4 061 ha**

Depth: The maximum depth of both variants was 2.5 m, with upper limits in the mid-tidal zone. The maximum tolerance to air exposure was not determined, but appears to be over 50% of the time from casual observation.

Substratum: Both forms were found on substrata ranging from fine sand, commonly in intertidal areas, to black organic oozes often where permanently submerged in lagoons and rivers (see Figures 5.5 & 5.6).

5.2 Sample area profiles

The distribution of seagrasses within each zone is summarised here. The sample areas are grouped according to their habitat type, and the seagrasses found there are discussed.

5.2.1 Zone A - North coast and Bass Strait islands

All five seagrass species were found in this zone, although their presence varied considerably with habitat type.

5.2.1.1 Open drainage systems

This includes the lagoons, tidal arms and tidal rivers of the region. The dominant species in these habitats is *Zostera muelleri* which may cover intertidal sandbars and flats. *Heterozostera tasmanica* can be found occasionally on the bed of channels or as a fringe along their edges. In Duck Bay (3) (Map 5.7) and Port Sorell (19) most of the *Z. muelleri* has been lost (Chapter 6), however West Inlet (4a) and East Inlet (6a) together have around 300 ha. of *Z. muelleri* beds (Map 5.8).

The tidal flats of North East River on Flinders Island are similarly colonised by *Zostera muelleri*. Cameron Inlet and Logan Lagoon were not adequately sampled to form a clear picture, but aerial photographs indicate they also have *Z. muelleri* beds. Species of *Ruppia* were found in Cameron Inlet.

5.2.1.2 North coast exposed and semi-exposed beaches and bays

Although sampling in this region was not as comprehensive as in the south east, most of the significant underwater features revealed by studying aerial photography were inspected. Based on Hughes and Davis' (1989) compilation of past records, it was anticipated that a broad swathe of *Posidonia australis* covered much of the north coast subtidal zone. However, within the depth range of this study, few beds of *P. australis* were found in these habitats.

The most common seagrasses were small areas of *Amphibolis antarctica* and *Heterozostera tasmanica* protected by the large stretches of offshore reef that occur, in particular, between Rocky Cape and Point Sorell, and east of the

Tamar to Bridport. Other areas of exposed coast were extensive sweeping sandy bays such as Perkins Bay and Sawyer Bay in the west, and Andersons Bay and Ringarooma Bay to the east. Little evidence of seagrass was found here either in the water, through beach searching or from aerial photographs.

Exposure to wave action is the most likely limiting factor in these areas, since almost all inspections of sandy substrates in the lee of small islands and rocks, or in the shelter of headlands revealed at least patches of *A. antarctica, H. tasmanica* or *P. australis* (i.e. areas 8, 11, 18, 21, 27). Due to their small size none of these regions have been mapped.

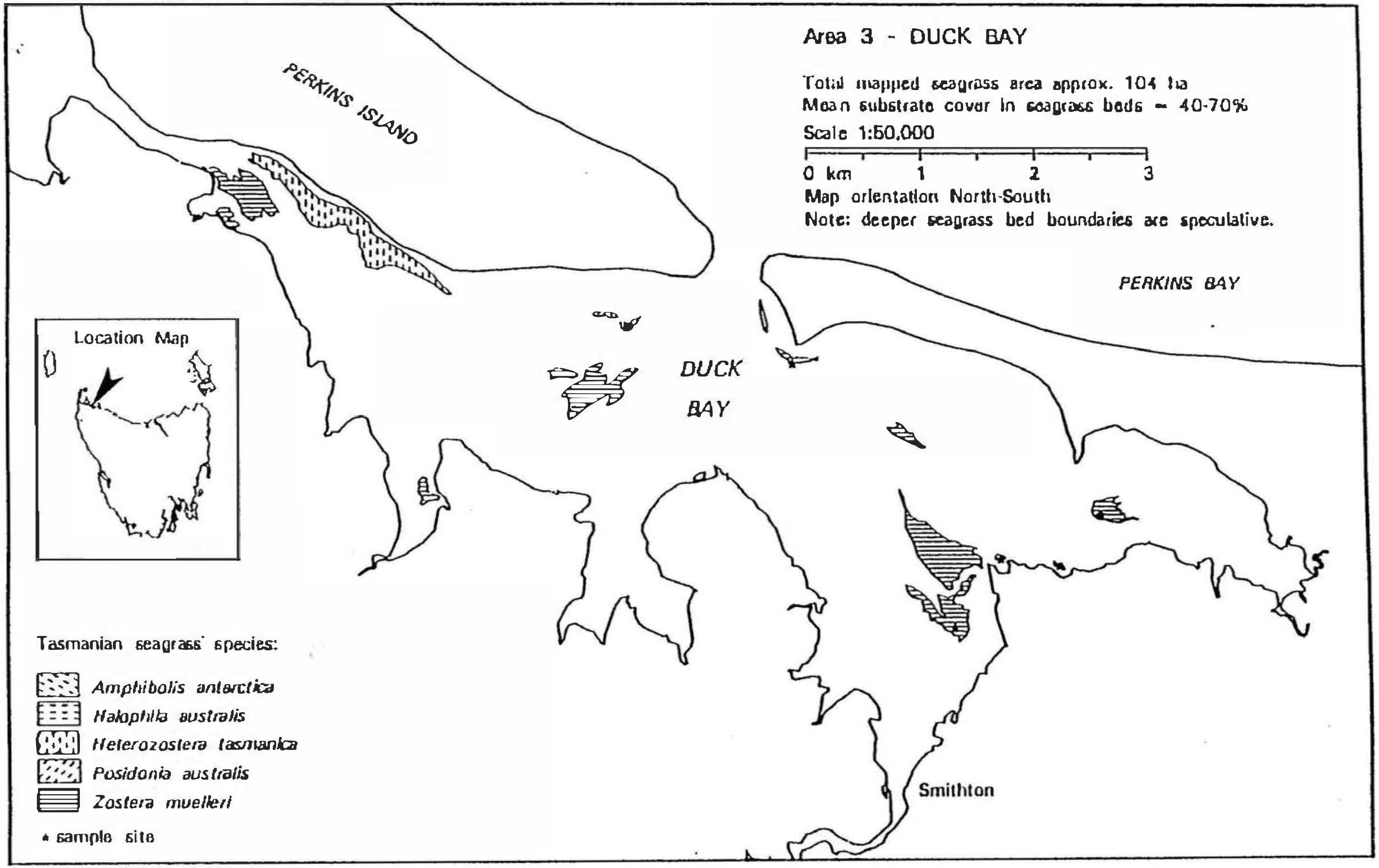
5.2.1.3 Sheltered offshore areas and the Tamar Estuary

This group of sample areas includes the most extensive seagrass beds in Tasmanian waters. Over 120 km2 has been identified and mapped in the four areas Woolnorth Point to Robbins Island (1&2) (Map 5.9), Port Dalrymple (22) (Map 5.10), and Parrys Bay (146) (Map 5.11) and Adelaide Bay (147) (Map 5.12) on Flinders Island. These areas are characterised by shallow sandbanks dominated by *P. australis*, with significant areas of *H. tasmanica* and *A. antarctica.* The true area is certainly much greater than this since a number of beds were identified on aerial photographs but could not be sampled or mapped due to time constraints. These include other regions of the Furneaux Group, Swan Island in the north east, and between Robbins Island and Perkins Island in the north west.

The Tamar Estuary, or Port Dalrymple (22), has similar large areas of shallow *P. australis* beds near the mouth, and a declining patch upstream from Beauty Point. There are associated beds of *A. antarctica* and *H. tasmanica.* Waterhouse Passage (29) has important beds of *A. antarctica* and some *H. tasmanica.*

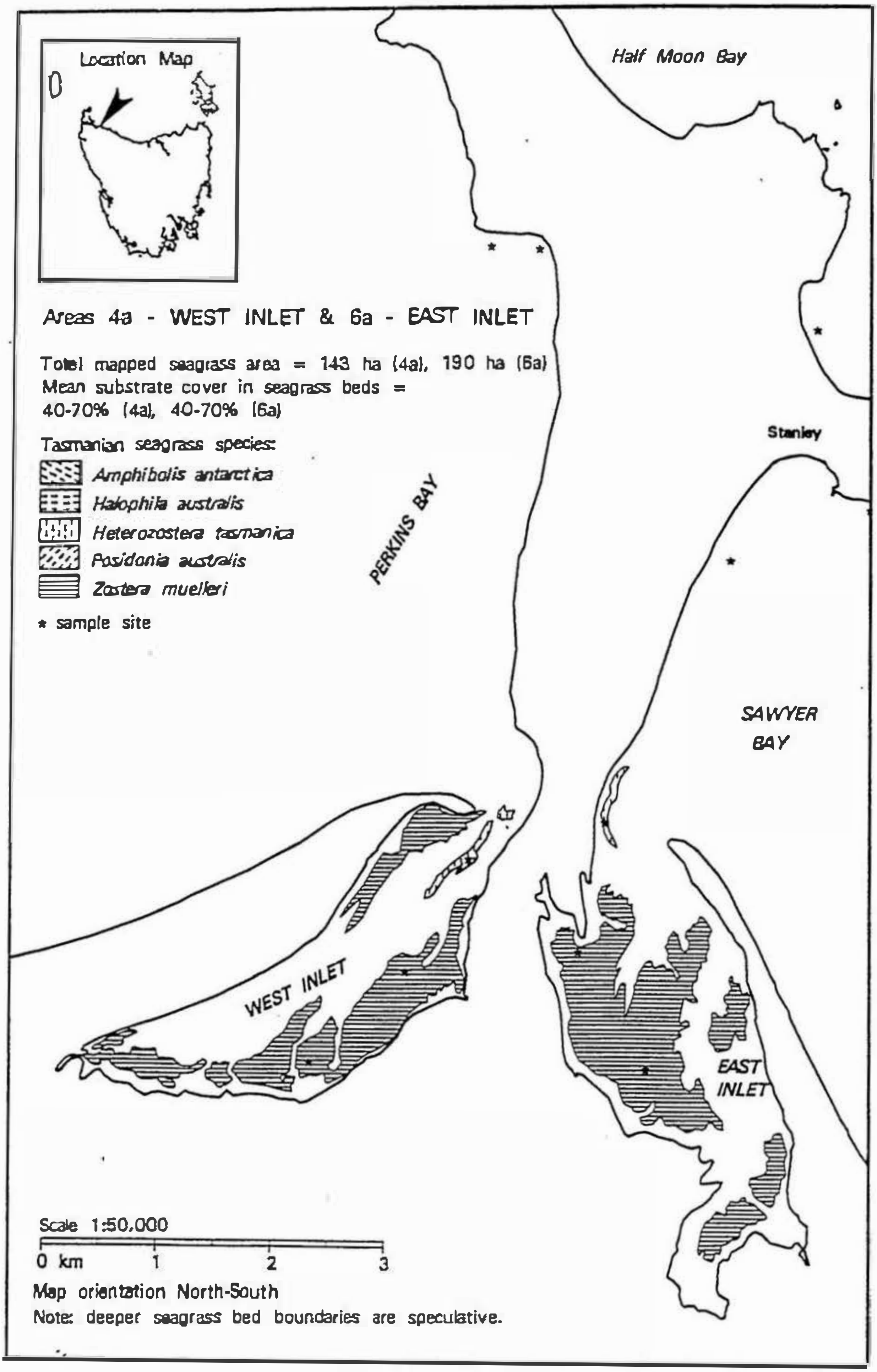
Most of these coastal areas also have beds of *Z. muelleri* on suitable intertidal flats, and *H. australis* is often present in deeper channels (e.g. Flinders Island, J. Morgan, pers comm.) although these were not easily sampled from the surface.

(Maps 5.7 to 5.12 follow)



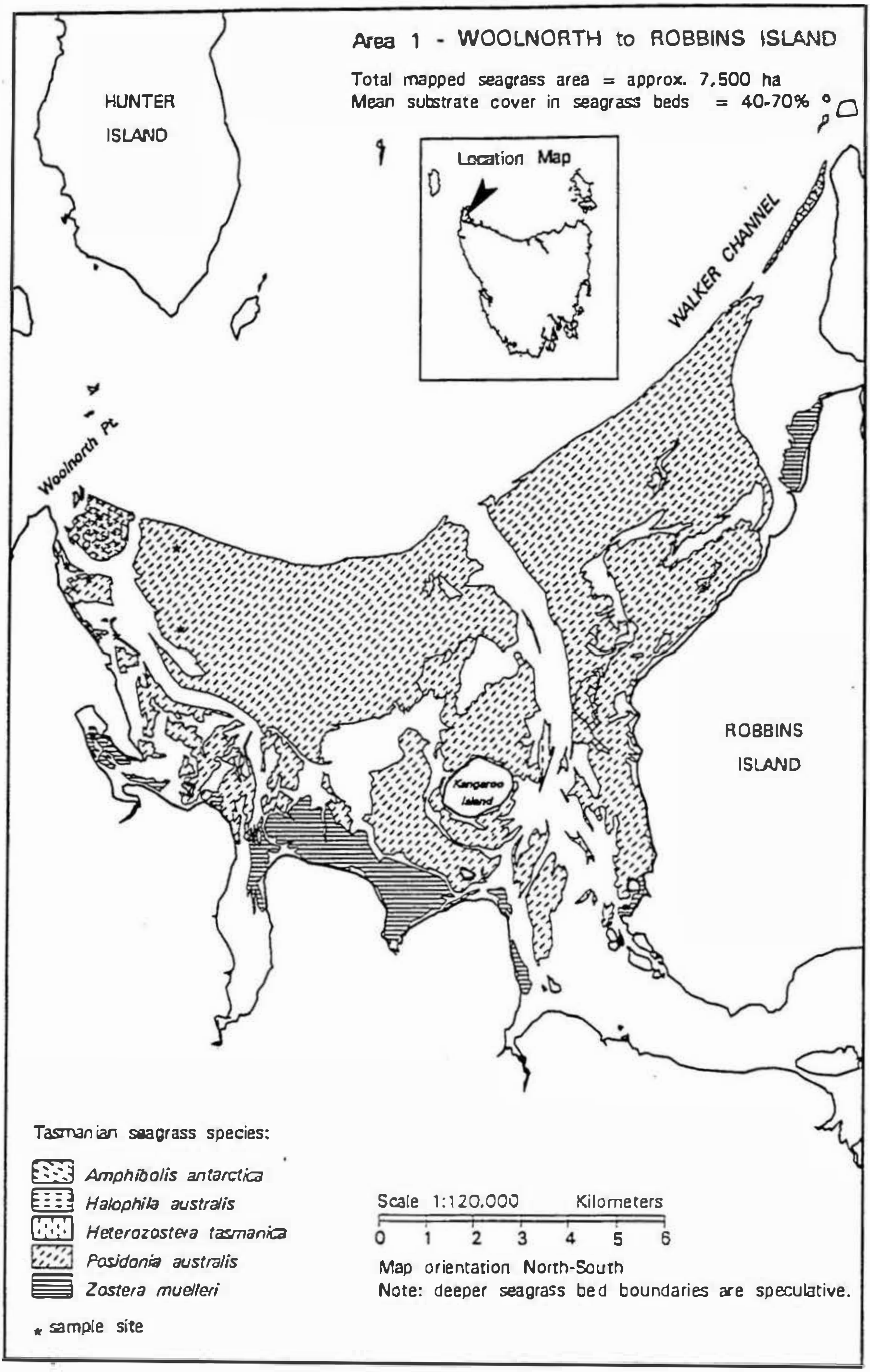
Map 5.7: Area 3, Duck Bay, present seagrass coverage

Map 5.8:
Area 4a, West Inlet & area 6a, East Inlet, present seagrass coverage



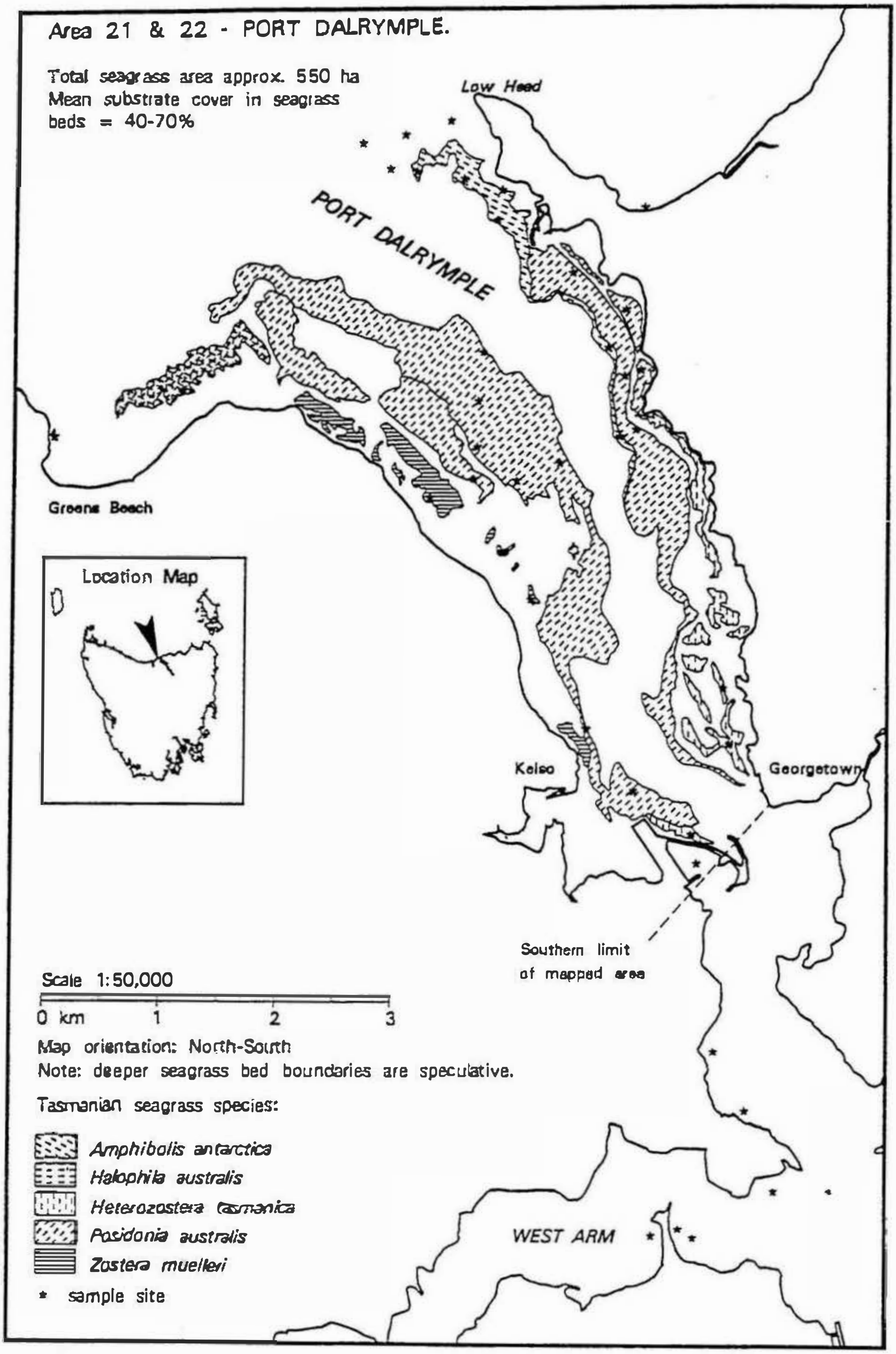
Map 5.9:

Area 1, Woolnorth to Robbins Island, present seagrass coverage

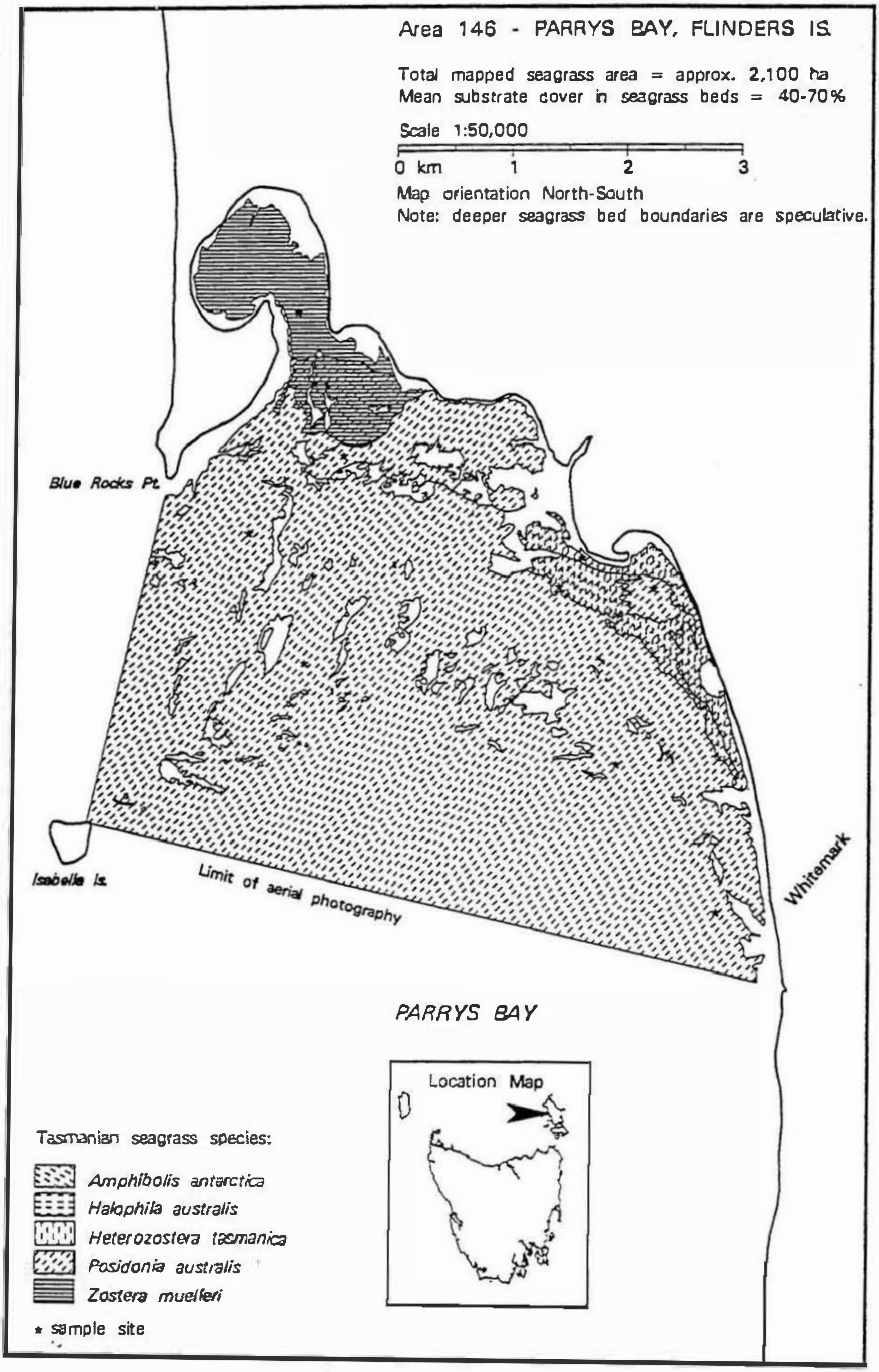


Map 5.10:

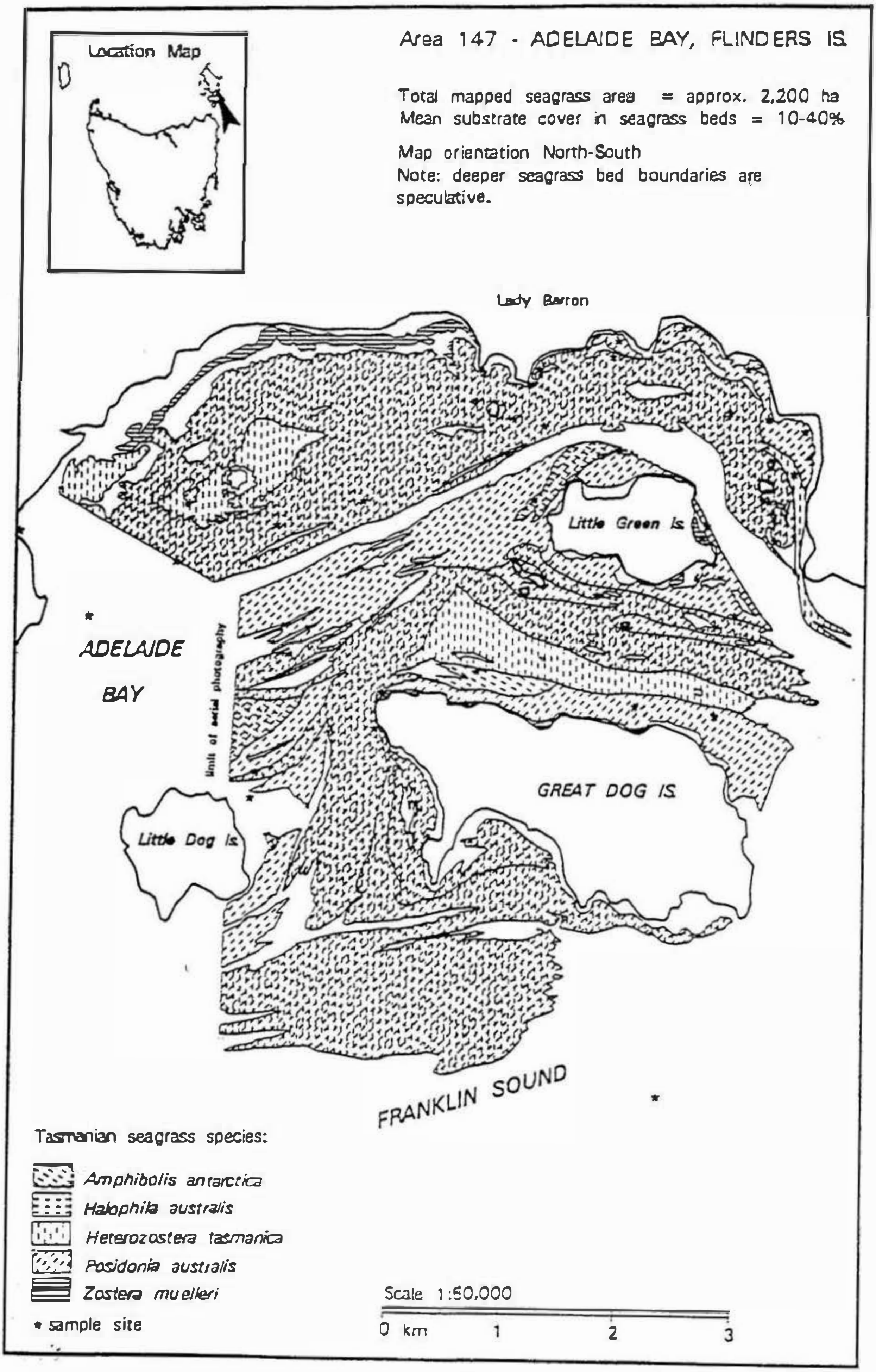
Area 21 &22, Port Dalrymple (Tamar), present seagrass coverage



Map 5.11:
Area 146, Parrys Bay (Flinders Island), present seagrass coverage



Map 5.12:
Area 146, Adelaide Bay (Flinders Island), present seagrass coverage



5.2.2 Zones B, C and part of D - East coast

5.2.2.1 East coast semi-closed and open drainage systems

The bar and beach dammed lagoons of the east coast provide habitat for *Zostera muelleri* and species of *Ruppia*. This includes the series of small lagoons in the St. Helens region, namely Big Lagoon (39), Sloop Lagoon (40), Grants Lagoon (41), Dianas Basin (44), Wrinklers Lagoon (46), and Hendersons Lagoon (49). Seagrasses are very sparse in some cases, perhaps due to eutrophic, or dystrophic conditions in these water bodies.

Habitats classified as open lagoons, tidal arms and estuaries on the east coast include Mussel Roe Lagoon (35), Little Mussel Roe Lagoon (33), Ansons Bay (38), Georges Bay (43) (Map 5.13), Moulting Lagoon (60) (Map 5.14), Little Swanport (65) (Map 5.16) and Blackman Bay (73) (Map 5.19). Scamander River (48) and Four Mile Creek (50) also fall into this group. As on the north coast *Z. muelleri* is commonly found on intertidal flats, and *Heterozostera tasmanica* near the entrances on the floor of channels or on the walls of channels if deeper than 2 to 3 metres. In the upper reaches of the larger water bodies *Ruppia* spp. may predominate, particularly in Moulting Lagoon (60) and Little Swanport (65).

5.2.2.2 East Coast Sheltered Bays

The topography of the Freycinet Peninsula (57, 58, 59) (Map 5.14), and Maria Island (71) (Map 5.15) has created lengthy sections of west-facing coastline protected from easterly storms. The water here is of marine origin, and in the shallow subtidal areas in these regions extensive beds of *Heterozostera tasmanica* and smaller patches of *Amphibolis antarctica* are found. *Halophila australis* also occurs, though it was only found in Coles Bay (59) in this part of the State, and *Zostera muelleri* is found in occasional small patches in the intertidal zone.

There are only very small beds of *A. antarctica* and *H. tasmanica* from Swansea to Buxton Point, where shelter from easterly weather is provided by reefs. Little Christmas Island similarly shelters Mayfield Bay. Partial protection is also provided by Schouten Island and the Freycinet Peninsula 20 km to the east. Otherwise this coastline falls into the exposed category.

Oakhampton Bay (67),Spring Bay (68), and Prosser Bay (69) are all protected by their topography and Maria Island to the east, and are classified as semi-sheltered bays (Map 5.15). They are suitable habitat for *H. tasmanica,* although this is in decline (see Section 6.1.3.4). Other semi-sheltered habitats are found in Pirates Bay (75) at the southern end, and parts of Fortescue Bay (76). These were not sampled in this study, although *H. tasmanica* has been recorded in both sites by other researchers in the lee of Fossil Island, Pirates Bay (Guiler 1952; Askey-Doran 1989), and up to 15 m depth in Fortescue Bay (P. Last, pers. comm.).

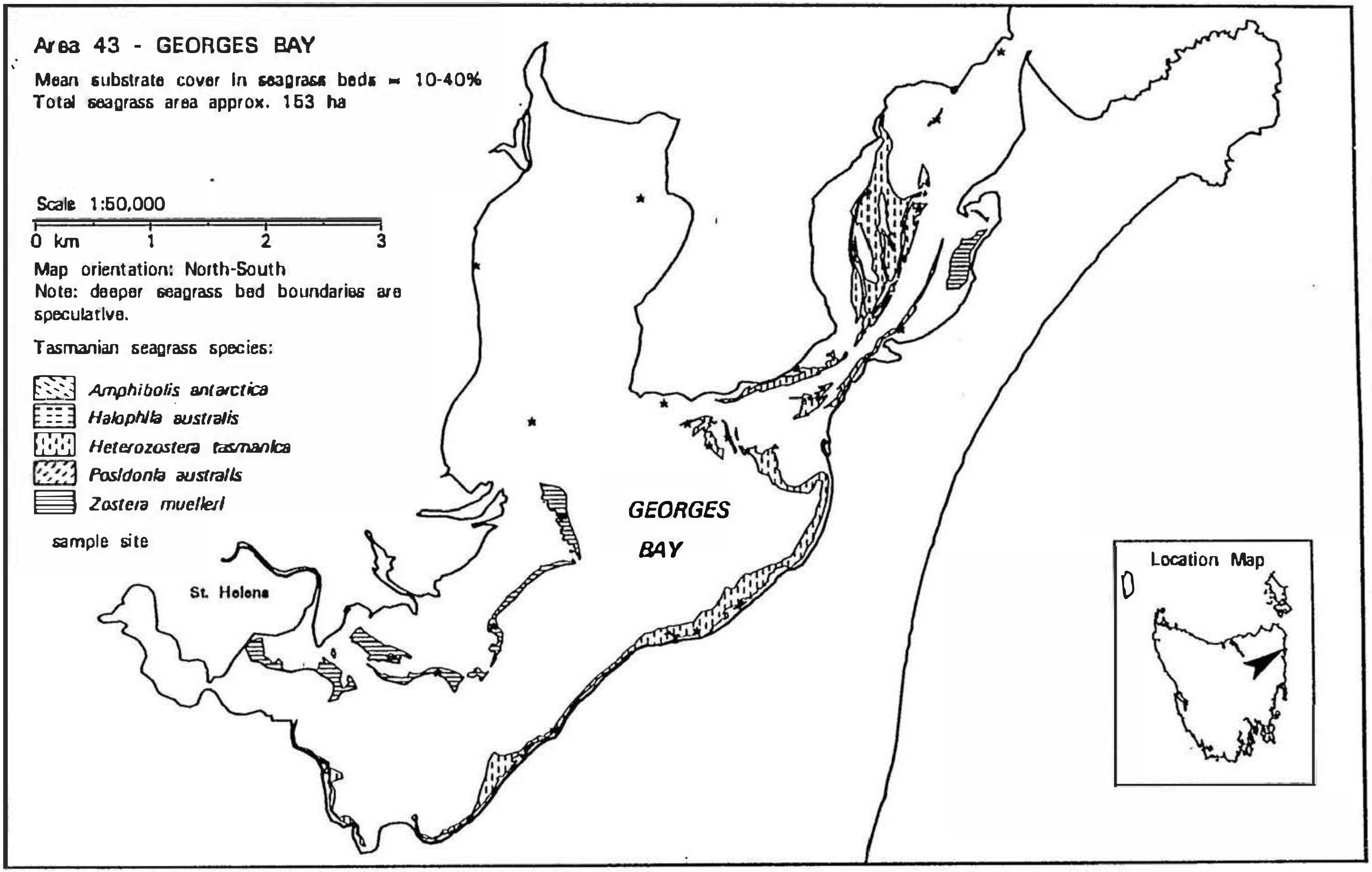
5.2.2.3 East coast exposed beaches and bays

The exposed east-facing coastline from Eddystone Point in the north east to Tasman Island in the south east provide little suitable habitat for seagrasses. The beaches along this coast were searched for evidence of offshore beds, but little was found. The most interesting examples were samples of *P. australis* and *A. antarctica* washed up at Scamander, Falmouth and Bicheno. The *P. australis* at Bicheno was an apparently fresh sample found near Diamond Island after a southerly gale had been blowing for two days. It is most likely, however, that this had drifted south from Swan Island or the Furneaux Group, although there remains a possibility that a small bed exists in the lee of an island such as St. Helens Island or Paddys Island off Scamander beach.

5.2.2.4 East coast offshore areas

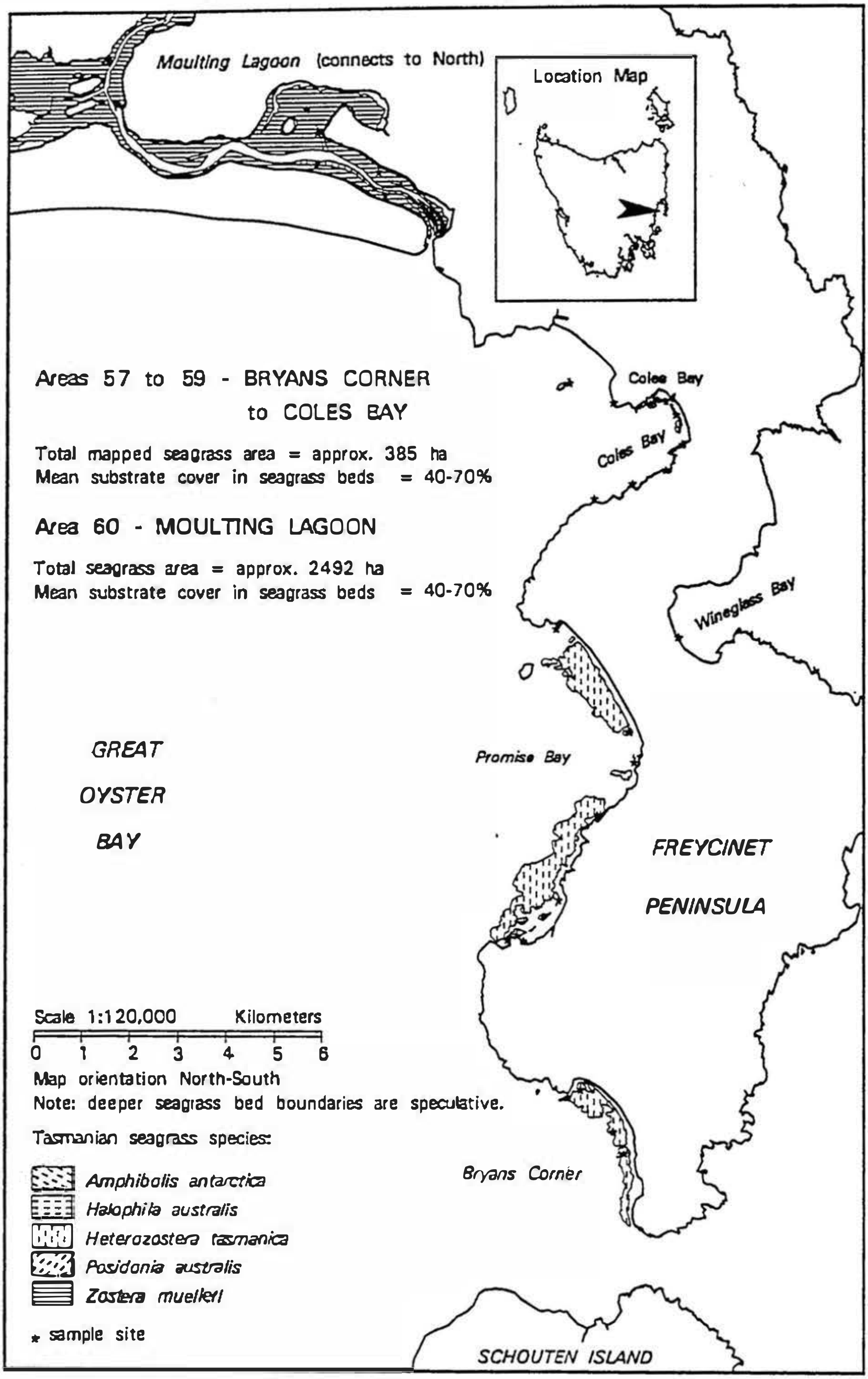
Some small patches of *Heterozostera tasmanica* occur around Lachlan Island in the Mercury Passage (Map 5.15), and an extensive sparse coverage of the species is reported growing on the shallow bed of parts of the Mercury Passage and Great Oyster Bay (N. Barrett, pers. comm.)

(Maps 5.13 to 5.16 follow)

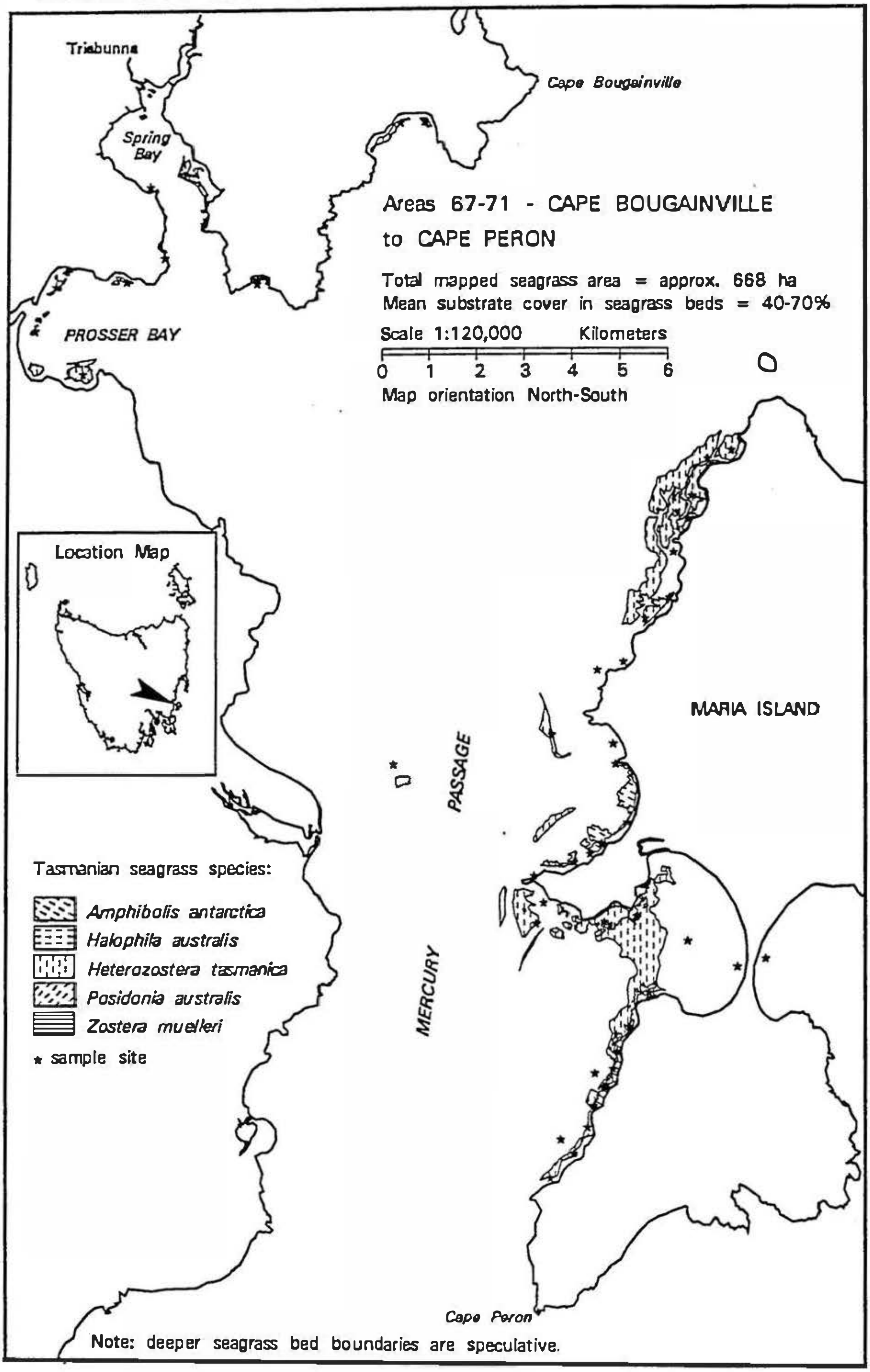


Map 5.13: Area 43, Georges Bay, present seagrass coverage

Map 5.14:
Areas 57 to 60, Bryans Corner to Moulting Lagoon, present seagrass coverage

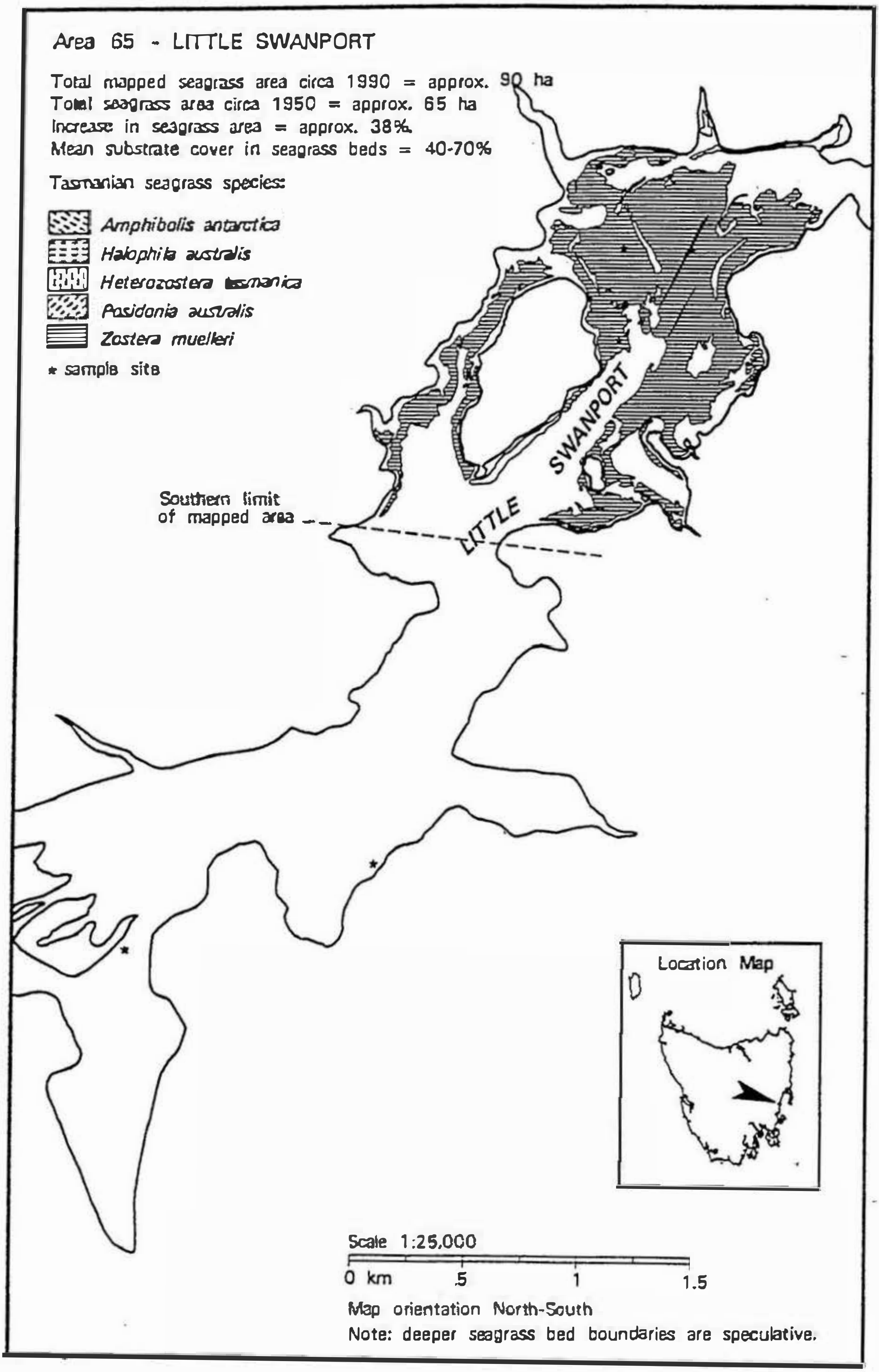


Map 5.15:
Areas 67 to 71, Cape Bougainville to Cape Péron, present seagrass coverage



Map 5.16:

Area 65, Little Swanport, present seagrass coverage



5.2.3 Zone D - South east

5.2.3.1 South East Lagoons

Following the pattern of tidal lagoons in other parts of the State, those in the south east have beds of *Zostera muelleri* on intertidal flats and shallow areas, and *Heterozostera tasmanica* on the beds and banks of channels. *Ruppia* species may also be present where fresh water enters lagoons through streams or rivers. Pittwater (90 & 91), Pipe Clay Lagoon (93), and Ralphs Bay (96 & 97) now have severely depleted seagrasses (see Section 6.1.3.4), but fit this pattern.

Southport Lagoon (111) and Cloudy Bay Lagoon (124) (Map 5.25) both have extensive seagrass beds including *H. tasmanica* and *Z. muelleri*.

5.2.3.2 South East Sheltered Bays

Port Arthur (Long Bay (77) & Carnarvon Bay (78)) (Map 5.17), and Wedge Bay and Parsons Bay (79) (Map 5.18) provide sheltered habitat on the otherwise extremely exposed coastline of the Tasman Peninsula. *Heterozostera tasmanica* is the dominant species here, growing in large beds in the protection of Carnarvon Bay, Long Bay and Parsons Bay. In Wedge Bay *Halophila australis* mixes with this species at the northern end of the beach. Also relatively protected from southerly swells is the bay of Sloping Main up to Sloping Island (80). *H. tasmanica* also forms large beds on the shallow sediments of this area.

The *H. tasmanica* and *H. australis* are abundant in the shallow sheltered waters of Norfolk Bay. They end abruptly at 1.5 to 2 m, forming a clear line off the numerous small sandy beaches on its western and southern shores. These areas include Lime Bay & Monk Bay (81), Ironstone Point to Deer Point (82), and Deer Point to Sympathy Point (83) Map (5.19). *Z. muelleri* can be found in small patches in the intertidal zone of these gently sloping beaches. A 1992 video transect at 8 to 10 m showed *Heterozostera tasmanica* and *Halophila australis* forming approximately 15% of the vegetation cover in association with the more abundant macroalga *Caulerpa* sp (80%) (F. Ruwald, pers. comm.).

On the eastern coastline of Norfolk Bay, *H. tasmanica* and *H. australis* were found fringing the shore of Eaglehawk Bay, Little Norfolk Bay (84) and King George Sound (86). The most extensive beds are found across the shallows off Dunally Bay (87), where large volumes of detached leaves wash up on the beach. *Z. muelleri* also occurs on sheltered intertidal sediments. In deeper water of 9 m, another video survey showed *Heterozostera tasmanica* and *Halophila australis* cover 80% of the substratum near Chronicle Point (F. Ruwald, pers. comm.).

Along the north shore of Norfolk Bay from Fulham Point to Spectacle Island (88

& 89) only a few very small sparse beds of *H. tasmanica* were found. Carlton River appears to have beds of *Z. muelleri*, but these were not sampled. In Frederick Henry Bay, small patches of *H. tasmanica* occur in the Tiger Head area, but no evidence of seagrass was otherwise found apart from *H. tasmanica* and *H. australis* detritus on Cremorne Beach.

5.2.3.3 Derwent Estuary, D'Entrecasteaux Channel & Huon

The sheltered bays of the Derwent Estuary, D'Entrecasteaux Channel and the mouth of the Huon River are colonised by *H. tasmanica* and *H. australis*. A narrow fringe of these species also grows subtidally in North West Bay (100) (Map 5.20) and the D'Entrecasteaux from Dennes Point to Little Taylor Bay on the western shore of Bruny Island (113 to 121). *H. australis* was not found in Great Taylor Bay in this survey (Map 5.25). The situation from Oyster Cove (101) (Map 5.21) to Three Hut Point (104) and in Port Cygnet (106) is similar. In this study both species were found to depths of 7 to 8 metres in these areas. Edgar (1984b) recorded *H. ovalis* in shallow water and *H. tasmanica* in patches in the bays off Woodbridge (It is probable that *H. australis* was in this case mistakenly identified as *H. ovalis*, which has not been identified in this study). *Z. muelleri* was found also, but favouring shallower or intertidal sites on sheltered beaches and near fresh water influxes. This species also dominates the Derwent above Bowen Bridge (98), the Huon River above Brabazon Point (108) and Hastings and Ida Bays (110) (Map 5.23).

The River Derwent from Bowen Bridge to Tinderbox (99) has been impacted too heavily to form a clear picture, but remnant stands of *H. tasmanica* do occur, for example just south of Wrest Point. Edgar (1984b) found *H. tasmanica* and *H. australis* as patchily distributed below 5 m in Tinderbox Bay and Tinderbox Beach. This survey did not sample those areas

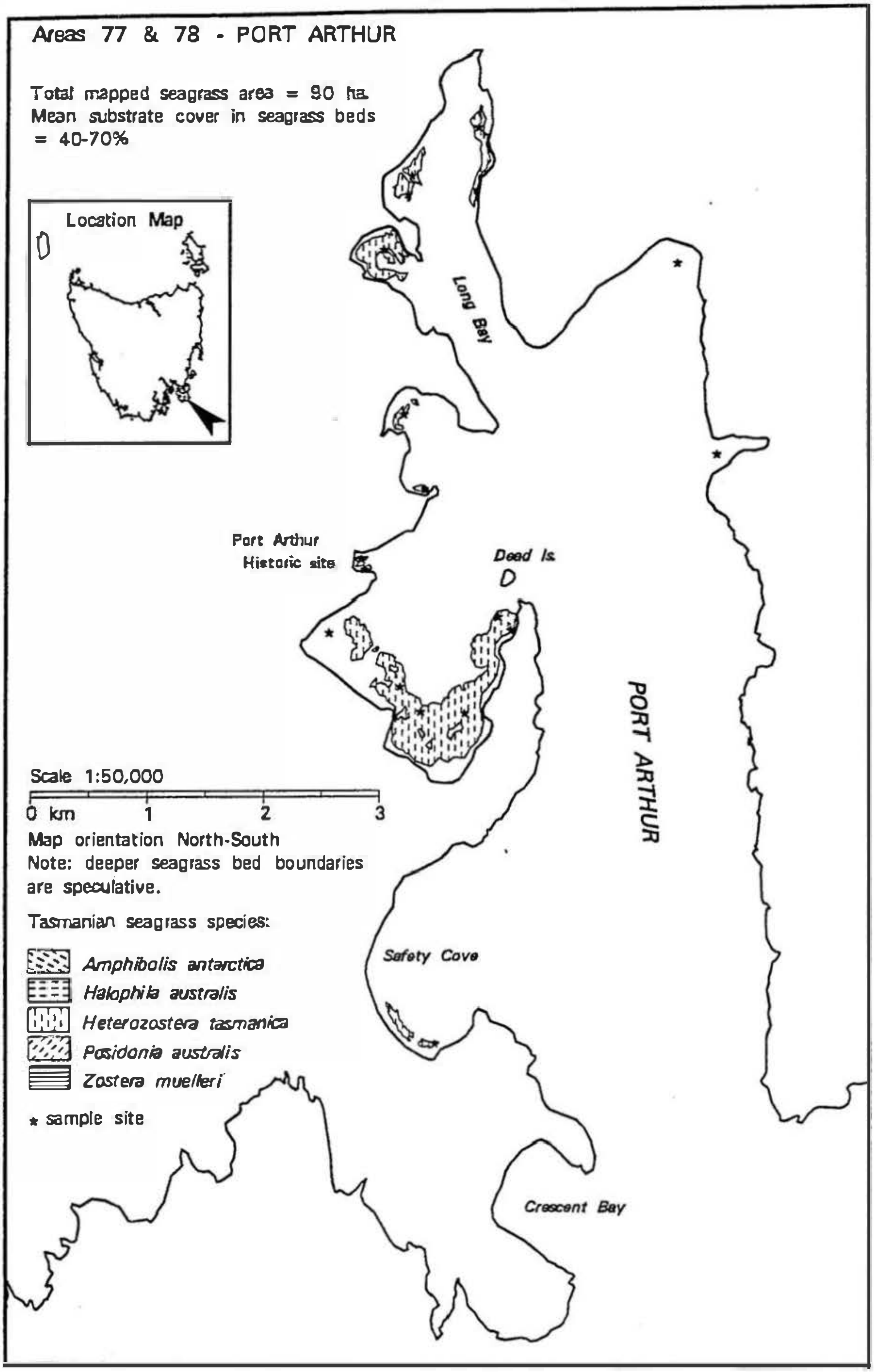
Port Esperance (109) (Mp 5.22), Southport (110) (Map 5.23) and Recherche Bay (112) experience the impact of strong ocean swells on some shores which tend to be rocky and dominated by macroalgae, but stands of *H. tasmanica* grow in more sheltered areas. Pigsties Bay in Recherche Bay is an example, with a large bed of this seagrass, although this only grows to 2 m depth due to high tannin levels in the water. Tannins similarly reduce the depth range of seagrasses in Hastings Bay and the Huon River.

5.2.3.4 South East Exposed Beaches

The beaches exposed to southerly swells on the coast of South Arm (Cape Deslacs to Cape Direction (94)), Bruny island (Cloudy Bay (123)) and the Tasman Peninsula showed no evidence of offshore seagrasses when searched for detritus.

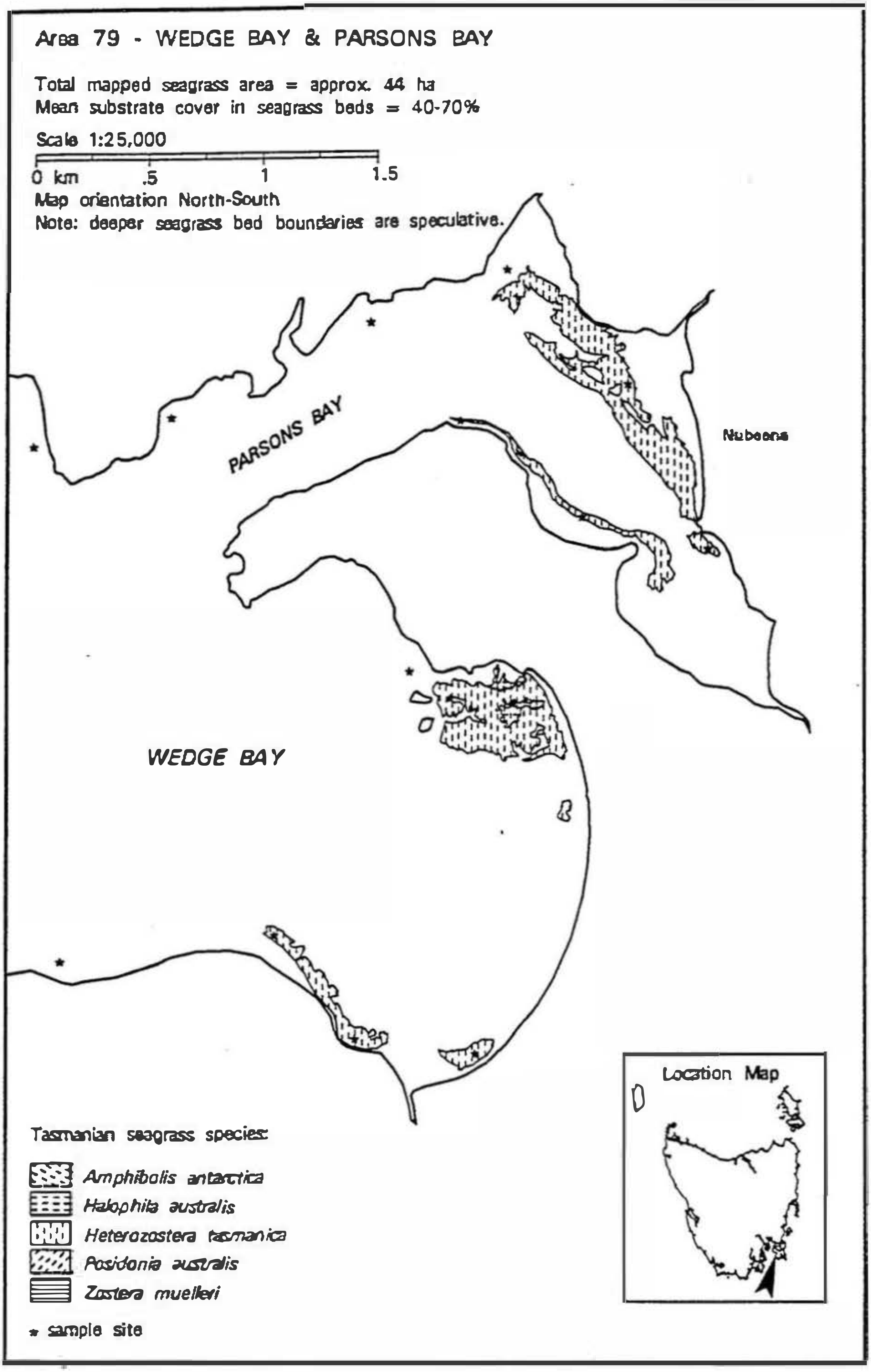
Map 5.17:

Areas 77 & 78, Port Arthur, present seagrass coverage

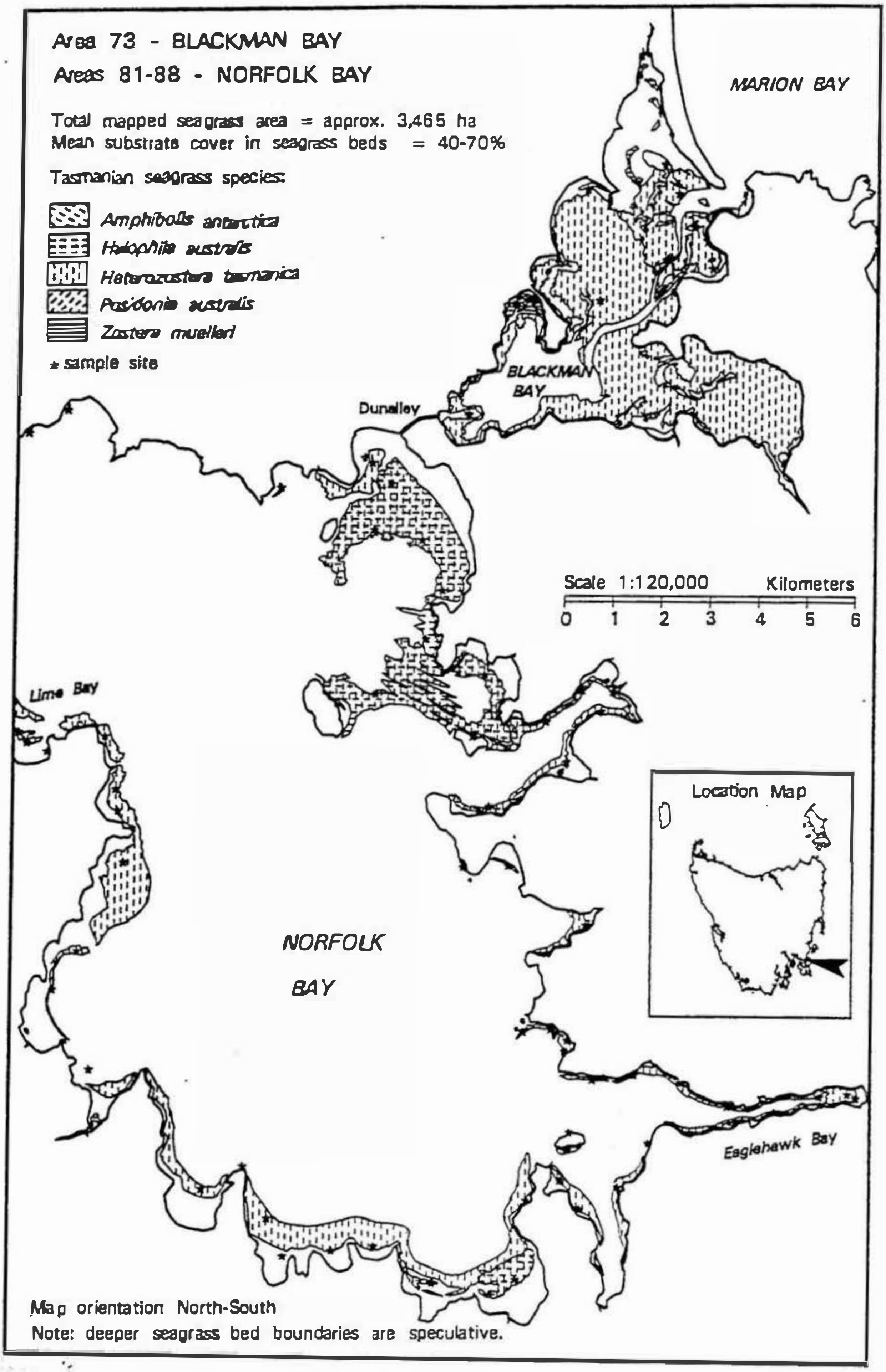


Map 5.18:

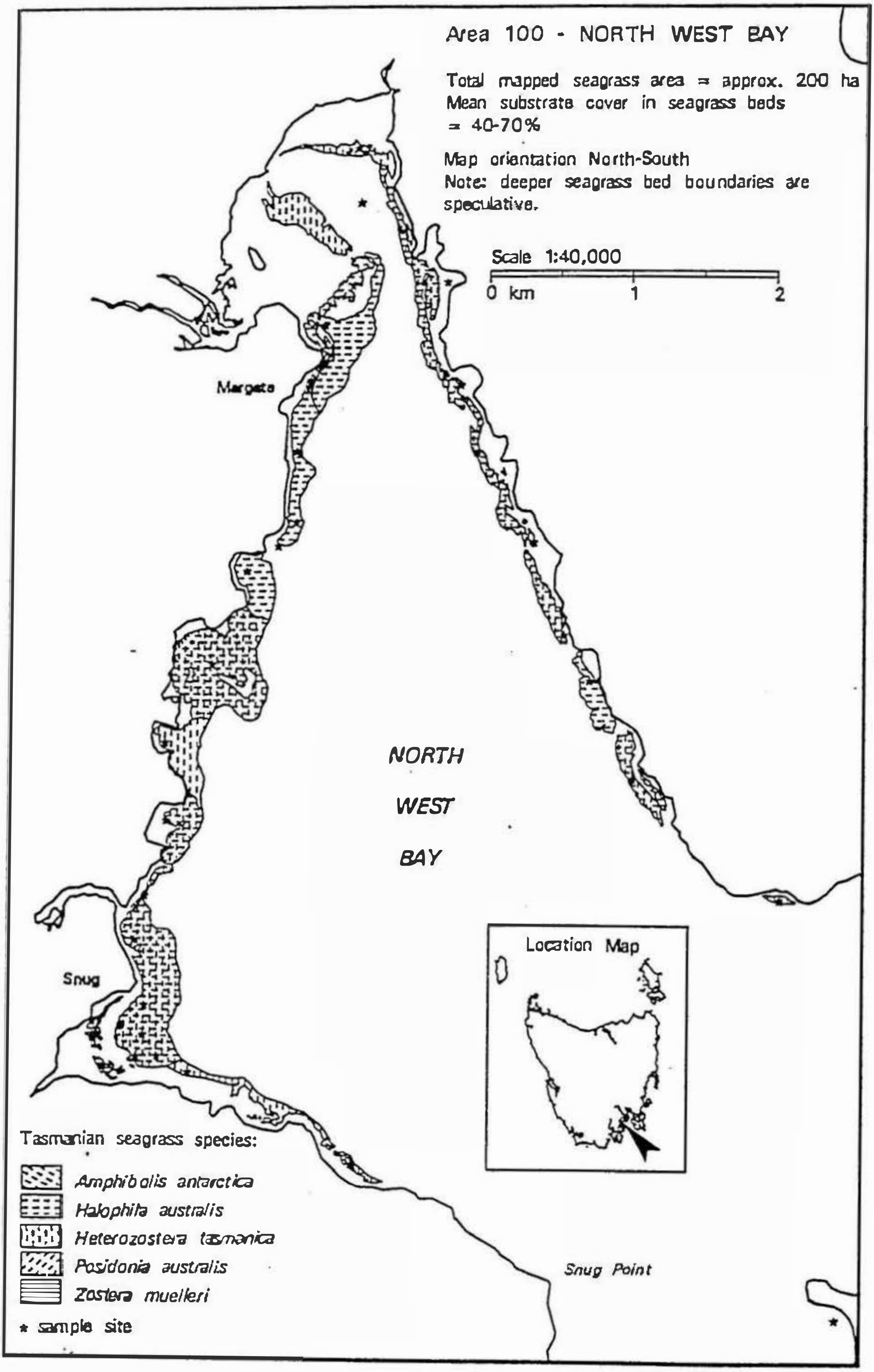
Area 79, Wedge Bay and Parsons Bay, present seagrass coverage



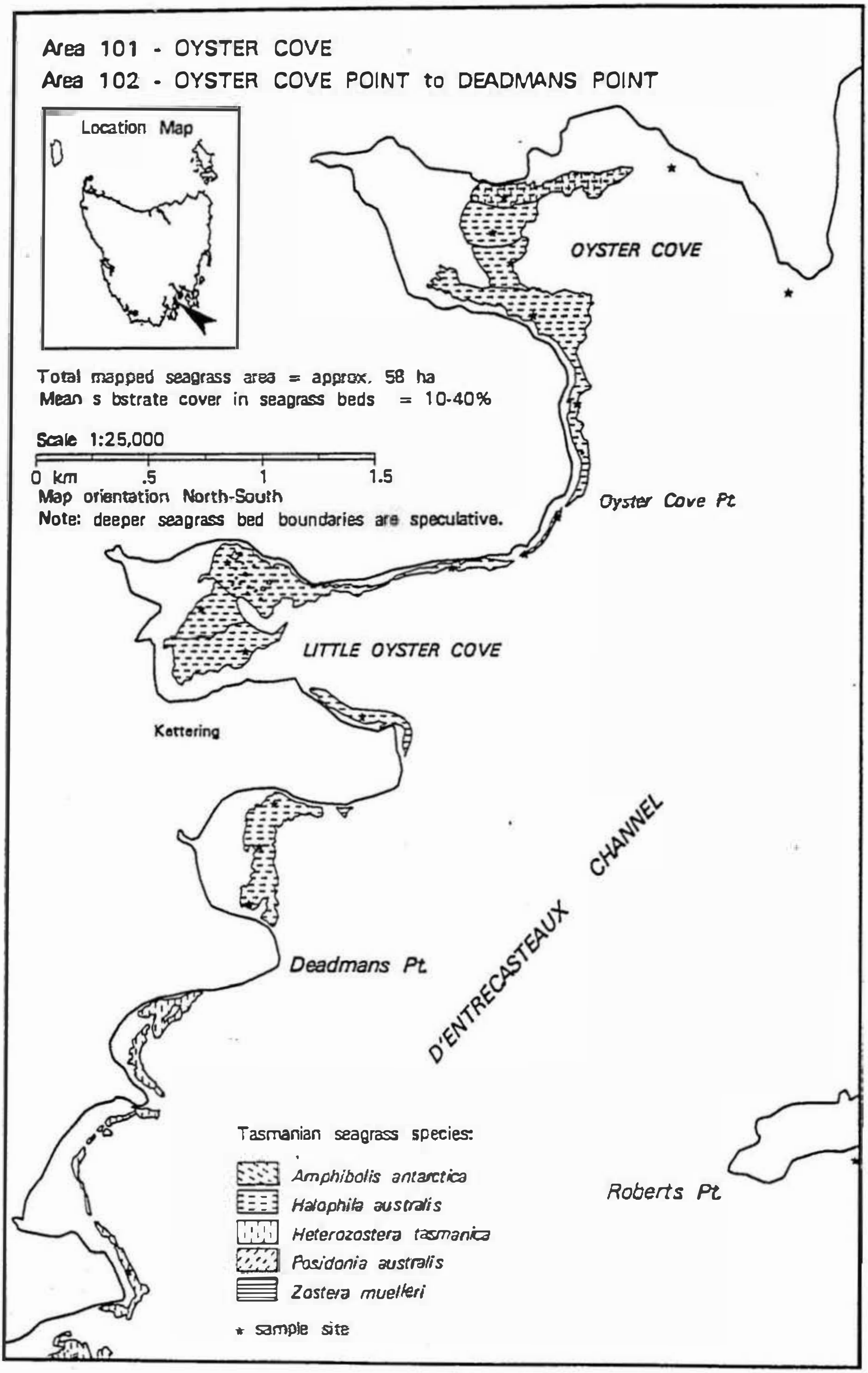
Map 5.19:
Area 73 Blackman Bay, & areas 81-88, Norfolk Bay, present seagrass coverage

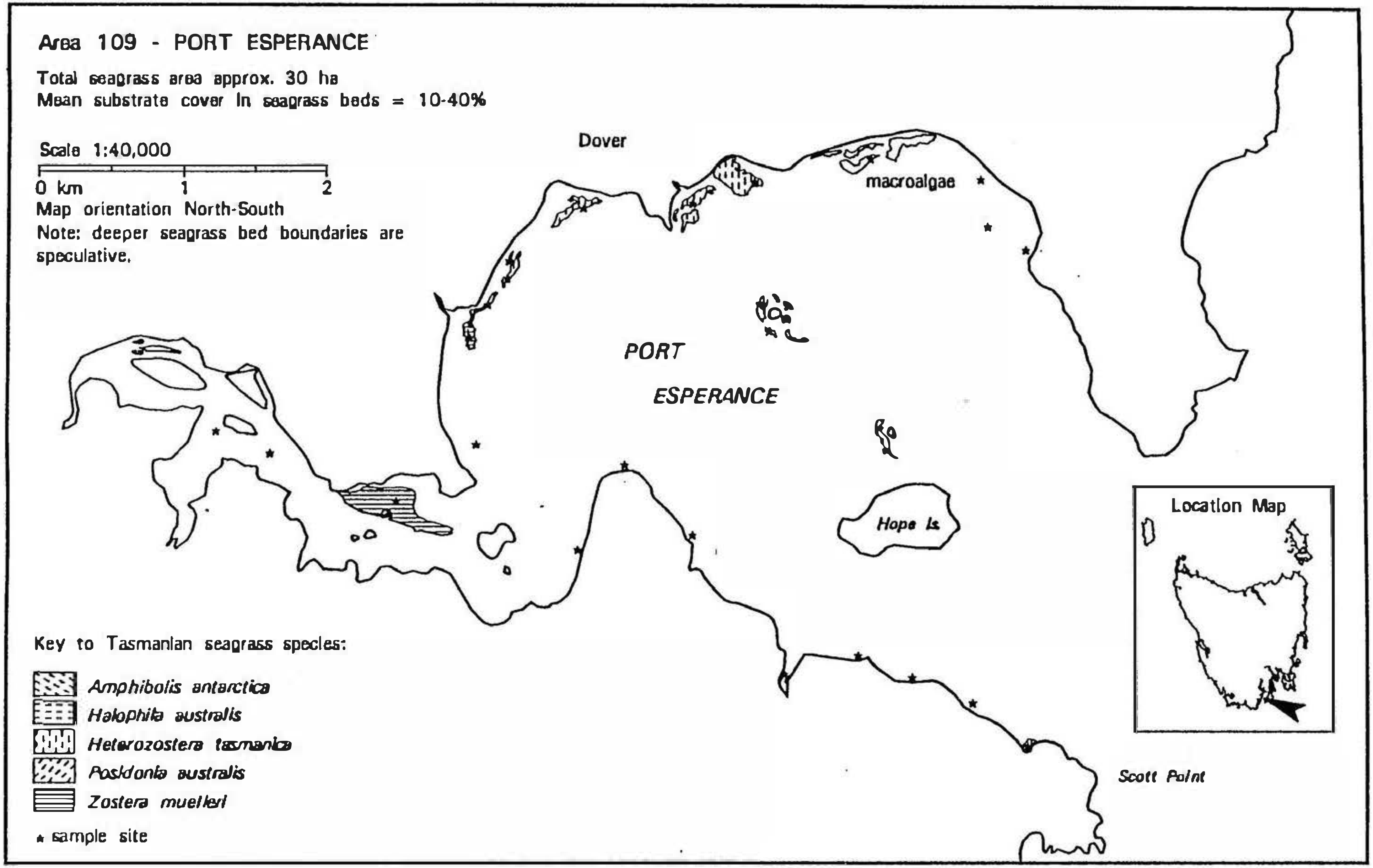


Map 5.20:
Area 100, North West Bay, present seagrass coverage

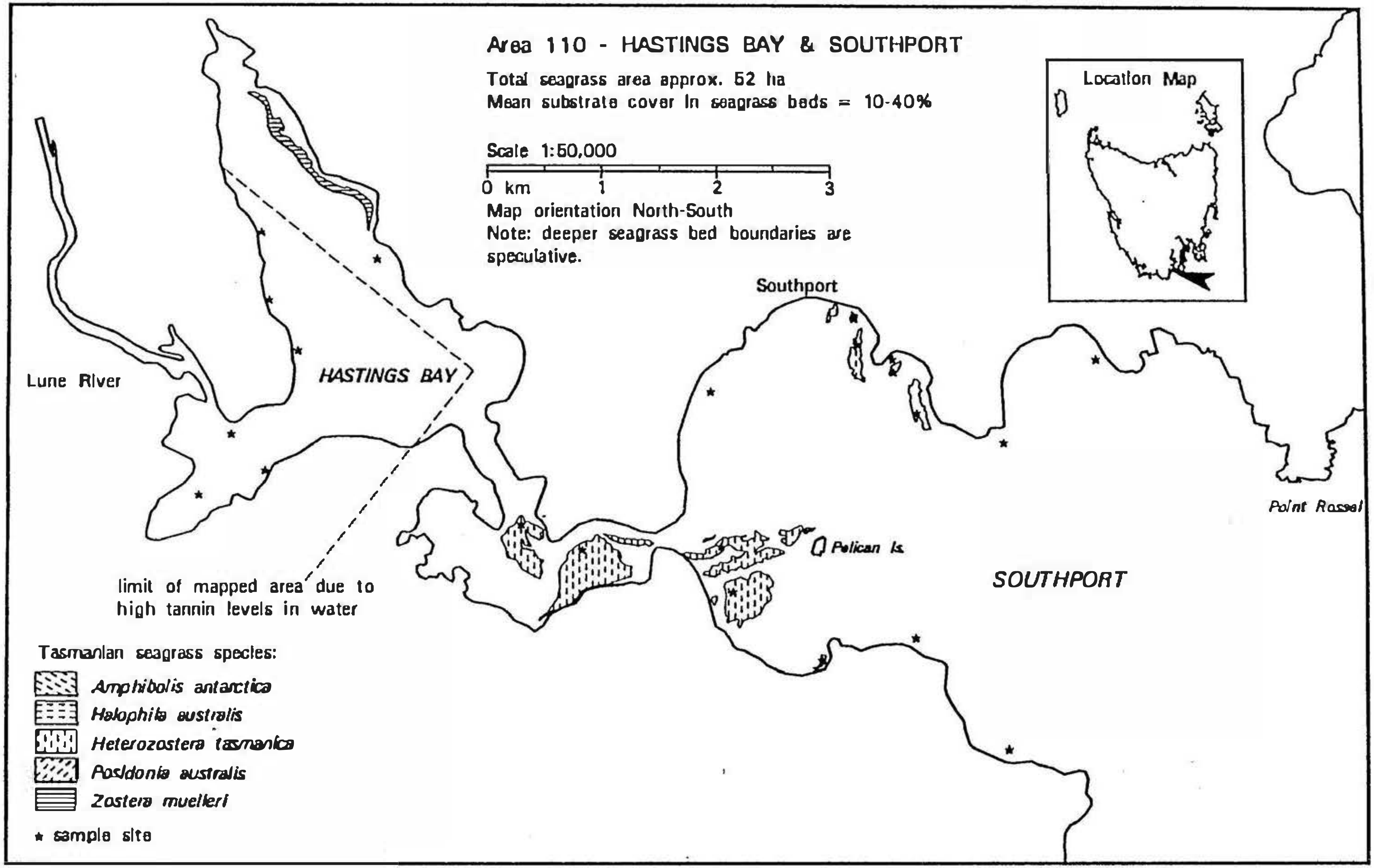


Map 5.21:
Areas 101 & 102, Oyster Cove to Deadmans Point, present seagrass coverage



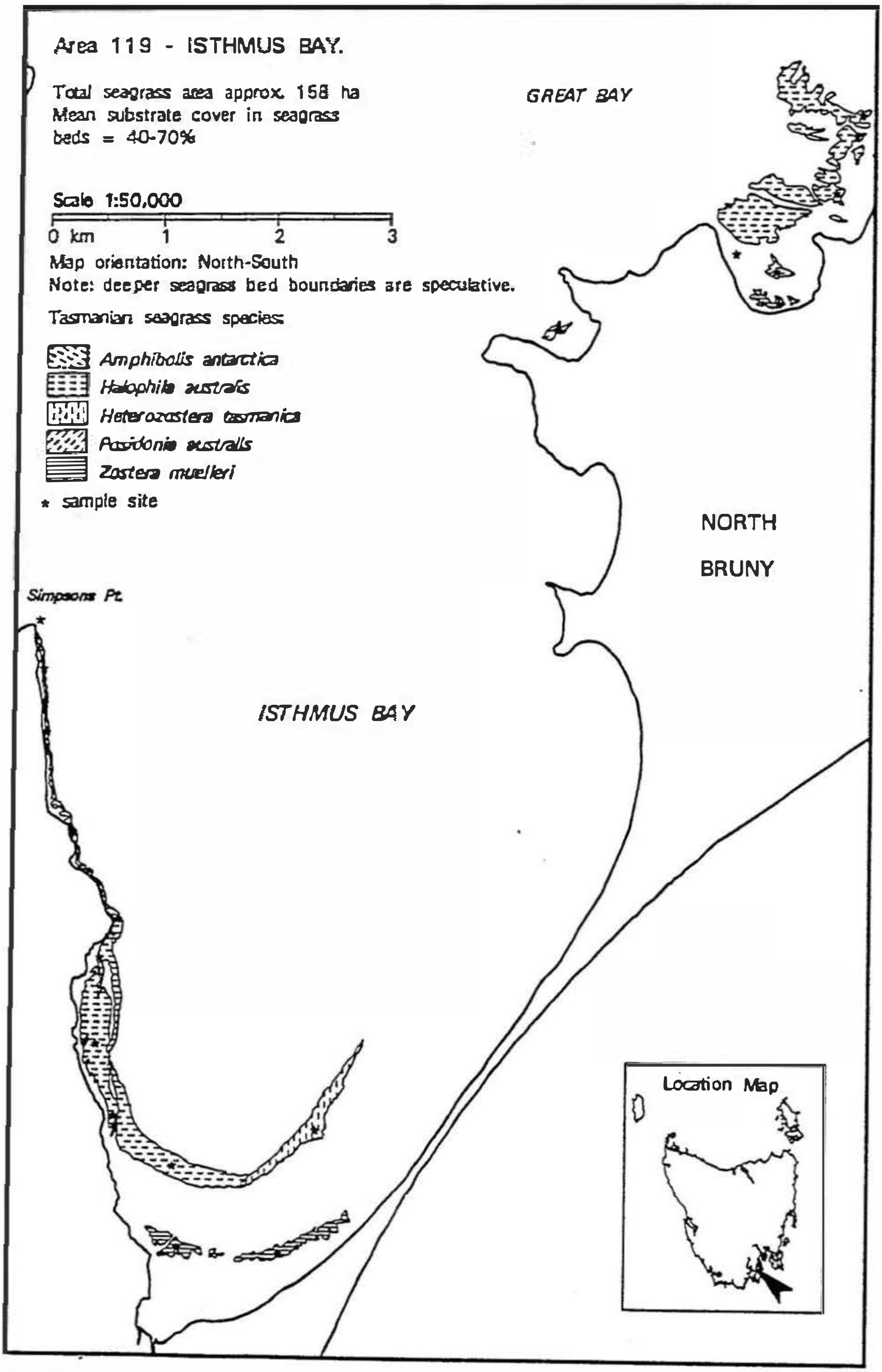


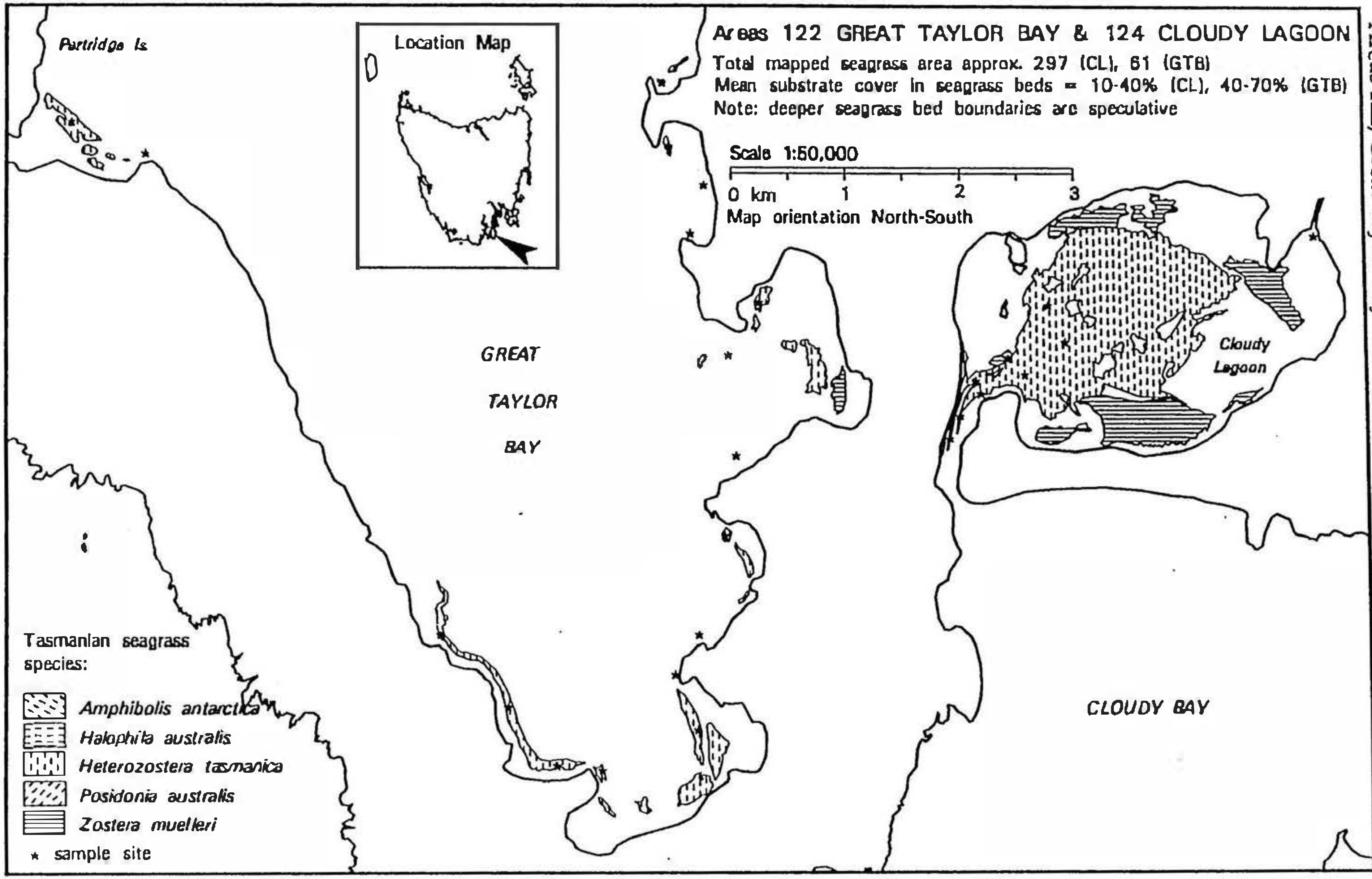
Map 5.22: Area 109, Port Esperance, present seagrass coverage



Map 5.23: Area 110, Hastings Bay & Southport, present seagrass coverage

Map 5.24:
Area 119, Isthmus Bay, present seagrass coverage





Map 5.25: Areas 122, Great Taylor Bay & area 124, Cloudy Lagoon, seagrass coverage

5.2.4 Zone E - South coast, south west & west coast

5.2.4.1 Open drainage systems

The rivers and lagoons of the west and southwest of Tasmania are deeply stained with tannins derived from the humic soils of the region. In addition, the high rainfall tends to maintain a layer of this tea-coloured fresh water above any tidal influx of saline water. The effect of this on seagrass communities is to greatly narrow their vertical range to 0.25 to 2.5 m, and in the upper layers to support aquatic species not otherwise found so close to a marine environment. Hence, in the Bathurst Harbour area species of *Ruppia* and *Lepilaena* are found with *Zostera muelleri* and *Z. muelleri sensu stricto* to depths of 1 to 1.5 m, and *Heterozostera tasmanica* to 2.5 m. Below 1.5 m *Caulerpa* sp. occurs in some areas. This pattern is a broad tendency reflected most clearly in Kelly Basin (127), Hannant Inlet (129) and the seaward end of Bathurst Channel (130).

Kelly Basin has a broad fringe of *H. tasmanica* on all but the eastern shore, with *Z. muelleri* along the shallows of the west shore, and *Caulerpa* sp. at 2 to 3 m extending up to 100 m into the bay. Hannant Inlet has only small beds of *H. tasmanica* in the northern seaward half, with *Z. muelleri* in the central narrows and almost complete domination by *Ruppia* sp. in the large shallow southern half. Horseshoe Bay (132) is similarly dominated by *Ruppia* sp. with some *Z. muelleri* at the entrance, and Joe Page Bay (131) has a fringe of *Zostera muelleri* dominated by *Ruppia* sp on the north eastern shore. The bays along the western half of Bathurst Channel (130) have patches of *Heterozostera tasmanica*, though none was found towards Bathurst Harbour.

Few seagrasses were found in Bathurst Harbour itself, but North Inlet (134) and Moulters Inlet (135) have both *Z. muelleri* and *Z. muelleri sensu stricto*. The largest beds of *Zostera muelleri* appear to grow in Melaleuca Inlet and the channel of Melaleuca Lagoon (136), particularly in Forest Lag and other broad sections of the inlet. These were free of epiphytes and up to 0.5 m in length. *Ruppia* was found in shallower water exposed by tide.

Mapping of this region from aerial photographs is not possible due to the staining of the water. However this survey confirms the ubiquitous presence of *Zostera muelleri* in the area, a species not recorded by Edgar (1983, 1989).

New River Lagoon (126) was not sampled, although it was inspected at 25 m altitude by light aircraft to identify the presence of underwater vegetation along the shoreline. Herbarium records note the occurence of *Ruppia* sp. on the eastern shore, but the aerial survey indicated that this is far from continuous around the lagoon.

The mouth of Maquarie Harbour (140) was sampled, including Fraser Flats, and the southern shoreline for approximately 2 km. Seagrasses were difficult to find due to the tannin staining of the water. The time of year, being early spring, may also mean that there were few leaf blades present, however, *Heterozostera tasmanica* occured near the entrance to Macquarie Harbour, *Zostera muelleri* was found along the southern shore in shallow bays, and *Z. muelleri sensu stricto* and *Z. muelleri* leaf blades were washed up on beaches towards Strahan.

5.2.4.2 Exposed beaches and bays

It was anticipated that conditions on the exposed west coast would prevent the establishment of seagrasses. This part of the state was not sampled for reasons of time and access, but *Heterozostera tasmanica* was positively identified from samples found during a geological survey of Granville Harbour (B. Goscombe, pers. comm.). Small beds grow in the shelter of offshore reefs there, and it is probable that this species occurs in a number of sites along that coast.

Last (1983), found no seagrasses in the Pieman River, and suggested that they seem to be totally absent from some west coast estuaries.

5.3 Discussion of present seagrass extent and distribution

5.3.1 The extent of seagrasses in Tasmania

A total of 226 km^2 was mapped in this study from recent aerial photographs. This is less than the full area of seagrass beds in Tasmanian waters, since many areas sampled had significant beds, and could not be mapped due to unsuitable, or unavailable aerial photography. Furthermore, large areas in the north west of Tasmania around Robbins Island, in the north east around Cape Portland and Swan Island, and in the Furneaux Group were neither sampled nor mapped. There are also a number of deeper areas where sparse *Heterozostera tasmanica* grows. Many of these unmapped areas are very extensive, and it would be reasonable to speculate that between 400 and 500 km^2 of seagrass beds grow around Tasmania.

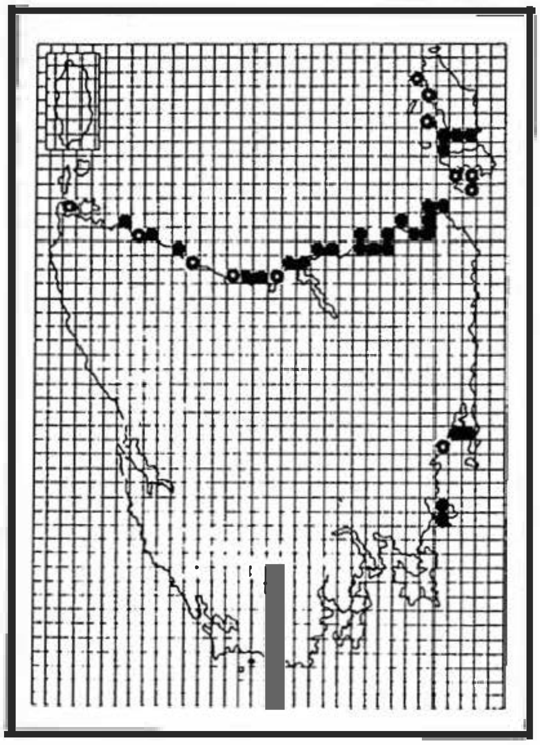
5.3.2 The distribution of seagrass species in Tasmania

A comparison of the distribution maps of the five seagrass species found in Tasmania produced by Hughes and Davis (1989) and the distribution maps of samples found in this study indicates a number of additions and uncertainties. These are discussed for each species below.

5.3.2.1 *Amphibolis antarctica*

The majority of the areas where *A. antarctica* is indicated on the 10 km grid maps of Hughes and Davis (1989) were confirmed in this survey, although some of the relevent areas on the north coast were not visited. Some additions were made to this range in zone A in the western half of the north coast, and in the Furneaux group. A further 10 km square was included in zone C on the east coast by the discovery of this species in Mayfield Bay on the western shore of Great Oyster Bay. *Amphibolis antarctica* therefore has a marginally more extensive range than thought earlier.

Map 5.26:
Updated 10 km distribution of *Amphibolis antarctica*
(after Hughes & Davis 1989)



● previous distribution (Hughes & Davis 1989)

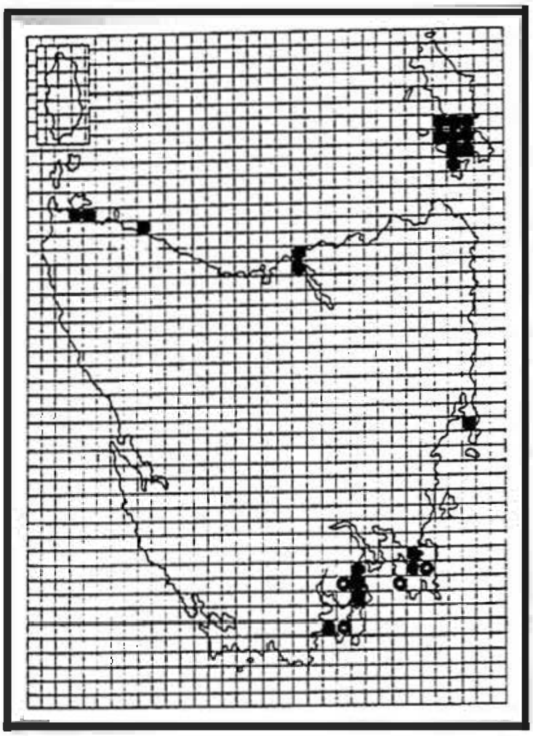
○ 10 km grid areas added in this study

5.3.2.2 *Halophila australis*

In zone A this species was only sampled in the Tamar and Furneaux Group. The north west as not sampled between Robbins Island and Perkins Island (2) where it is indicated by Hughes and Davis (1989), and it was not found in the Rocky Cape area (7 & 8).

In the south east of the State, additional 10 km grid squares can be added to its range due to sightings in Wedge Bay (79), Eaglehawk Bay (84), Port Cygnet (106), the D'Entrecasteaux between Oyster Cove (101) and Birchs Point (103), and around Alonnah (120) and Little Taylor Bay (121).

Map 5.27:
Updated 10 km distribution of *Halophila australis*
(after Hughes & Davis 1989)



● previous distribution (Hughes & Davis 1989)

○ 10 km grid areas added in this study

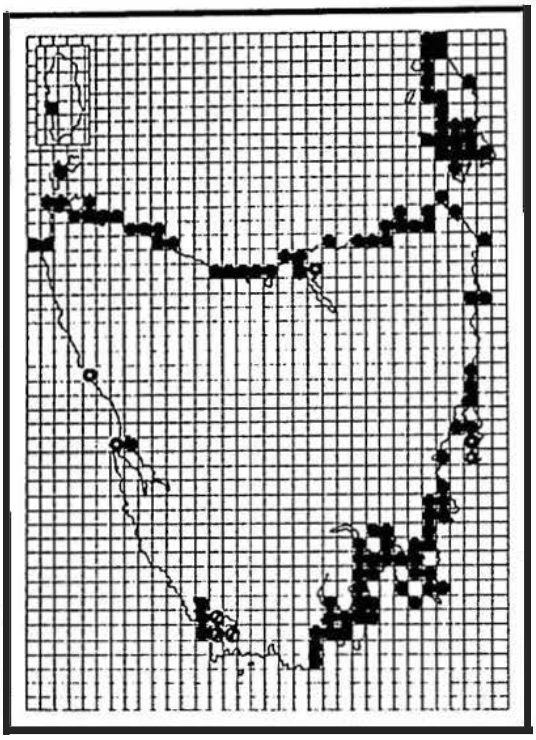
5.3.2.3 *Heterozostera tasmanica*

This species already had a very wide distribution suggested by Hughes and Davis (1989), occurring in all the five zones adopted in this study. However some additions and possible alterations are required.

An additional 10 km grid square in the Tamar region has been added due to samples collected in the Bell Bay region. New sites are added on the western shore of the Freycinet Peninsula with samples collected at Bryans Corner (57) and Promise Bay (58). On the west coast additions can be made at Granville Harbour (142) and the entrance to MacQuarie Harbour in the Kelly Channel area (139).

Changes to the earlier distribution are suggested in the Port Davey/Bathurst Harbour region where *Heterozostera tasmanica* was not found in the upper reaches of Bathurst Channel (130) and waterways in and around Bathurst Harbour (133 to 136). However, the presence of *Zostera muelleri* estuarine form and *Zostera muelleri sensu stricto* was confirmed in these areas. This suggests that *H. tasmanica* has been wrongly identified in previous studies.

Map 5.28:
Updated 10 km distribution of *Heterozostera tasmanica*
(after Hughes & Davis 1989)



● previous distribution (Hughes & Davis 1989)

○ 10 km grid areas added in this study

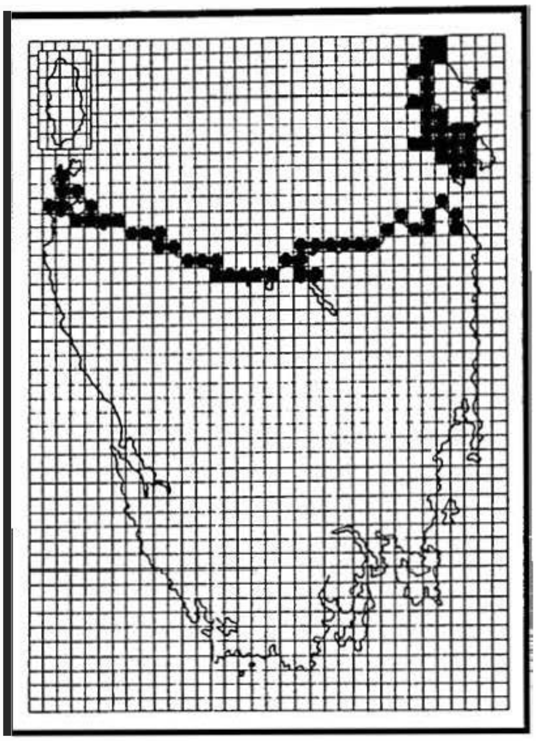
⊘ areas where species was not confirmed

5.3.2.4 *Posidonia australis*

According to the distribution map of Hughes and Davis (1989), this species occurs along the entire length of the north coast of Tasmania, and in all areas on the western side of the Furneaux Group. A number of these areas were confirmed in this study. However, the lack of samples of *P. australis* on the north coast, and the limited evidence of its presence in beach detritus suggests that further research is necessary to clarify its distribution. In particular, no evidence could be found between Port Sorell (19) and Rocky Cape (8), and from Bridport (28) to Waterhouse Passage (29), despite ground truthing most likely features on aerial photographs, and sampling to depths of 17 m where possible.

The range of *Posidonia australis* was confirmed as lying within zone A, although the find of a fresh sample in beach detitus at Waubs Bay, Bicheno (53), and at points further north on the east coast raise the possibility that small beds exist in that area. A future search of islands off Scamander Beach and Dianas Beach might resolve this issue, since these are probably the only suitable sites south of Eddystone Point.

Map 5.29:
10 km distribution of *Posidonia australis*
(Hughes & Davis 1989)



● previous distribution (Hughes & Davis 1989)

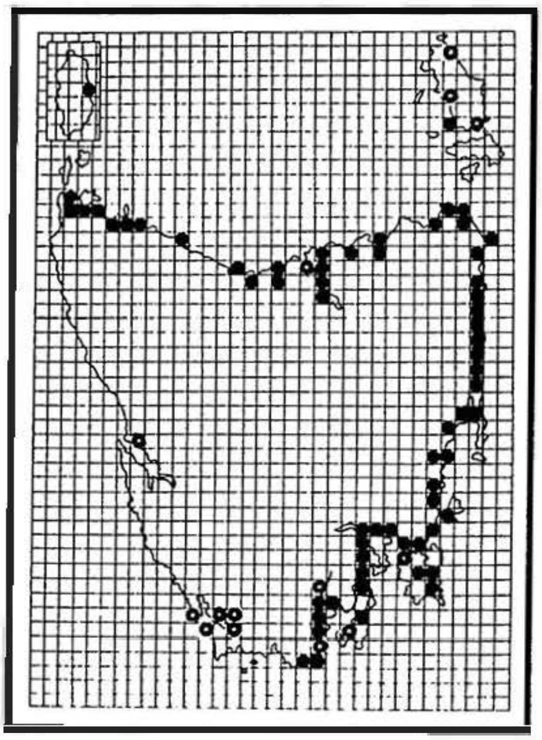
(no changes confirmed)

5.3.2.5 *Zostera muelleri*

A number of additions to the range of this species can be made as a result of sampling in this study. Hughes and Davis (1989) did not describe the smaller form *Z. muelleri sensu stricto*, and the presence of this variety adds to the species' range in zone E in both Macquarie Harbour (140), and the Port Davey/Bathurst Harbour region. In this latter area the larger estuarine form is also found, as described in section 5.1.5.

Other areas added to the previous known extent of the species are in the south east of the State, and in the Furneaux Group (Map 5.30). These are due to samples from Hastings Bay (110), the Huon River (108), Little Taylor Bay (121) and Lime Bay (81) in the south east, and Adelaide Bay (147), Parrys Bay (146) and North East River (149) on Flinders Island. One other area added is due to samples found on intertidal flats near Redbill Point in the Tamar (22).

Map 5.30:
Updated 10 km distribution of *Zostera muelleri*
(after Hughes & Davis 1989)



● previous distribution (Hughes & Davis 1989)

○ 10 km grid areas added in this study

Chapter 6
RESULTS - IMPACTS AND CHANGES

6.1 Mapping the current and past seagrass coverage

The discussion on the accuracy of sampling and digitising (section 4.6), and comments on the quality of aerial photography in the context of this project (section 4.3.2.1) are relevant to the results presented below.

6.1.1 Changes in seagrass extent

The lack of suitable aerial photography restricted mapping to a subset of sampling areas. Table 6.1 lists those areas mapped, and summarises the changes in each where applicable.

6.1.1.1 Coastal areas with stable or increased coverage

Some areas in zone C show an increase in seagrass cover since the late 1940s. *Heterozostera tasmanica* beds in Bryans Corner (57) and Promise Bay (58) on the Freycinet Peninsula appear to have increased from a combined area of 39 ha in 1949 to 334 ha in 1991 (see Map 5.14). This may in part be due to the poor quality of the 1949 photographs, but human impact on this area is unlikely, and the expansion of *H. tasmanica* beds over this time has precedent (e.g. Parry and Collett 1985).

Maps of the seaward half of Little Swanport (65) (see Map 5.16) showed a 38% increase from 65 to 90 ha between 1947 and 1990. Reports from a local oyster grower suggest there has been little change in recent years (C. Dyke 1991, pers. comm.).

Seagrasses in some other areas were mapped only in the present, but visual inspection of past aerial photographs suggests that little change has occured. These include:

(1) Woolnorth to Robbins Island
(4a) West Inlet
(4b) East Inlet
(29-35) The north east from Croppies Point, beyond Cape Portland to Little Mussel Roe Lagoon and Mussel Roe Lagoon.
(60) Moulting Lagoon
(111) Southport Lagoon
(146) Parrys Bay
(147) Adelaide Bay

Table 6.1:

Summary of coastal areas mapped, seagrass coverage and change over time

Area	Area	Coast	Years mapped			Mapped area (ha)			Area	%	% change
code	Name	type	c1950	c1970	c1990	c1950	c1970	c1990	change	change	per 10 yrs
1	Woolnorth I. to Kangaroo I.	8,11			1985	_	_	7500	_	_	
3	Duck Bay	7		1968	1990	_	466	104	-362	-78%	-35%
4a	West Inlet	4			1992	_	_	143	_	_	
6a	East Inlet	4			1992	_	_	190	_	_	
19	Port Sorell	5	1946		1990	69	_	0	-69	-100%	-23%
21/22	Greens Beach & Port Dalrymple	10, 5	1946		1991	677	_	550	-127	-19%	-4%
33	Little Mussel Roe Lagoon	4			1990	_	_	30	_	_	
35	Mussel Roe Lagoon	4			1990	_	_	95	_	_	
43	Georges Bay	5	1950		1992	295	_	153	-142	-48%	-11%
57	Bryans Corner	8	1949		1991	14	_	81	67	479%	118%
58	Promise Bay	9	1949		1991	25	_	292	267	1227%	292%
59	Coles Bay	8	1949		1992	22	_	12	-10	-45%	-11%
60	Moulting Lagoon	4, 5, 6			1992	_	_	2492	_	_	
62	Swansea to Webber Pt.	9			1992	_	_	11	_	_	
63	Mayfield Bay	8	1948		1992	6	_	4	-2	-33%	-8%
65	Little Swanport	5	1947		1990	65	_	90	25	38%	9%
67	Oakhampton Bay	8	1948		1990	19	_	11	-8	-42%	-10%
68	Spring Bay	8	1946	1966	1991	118	48	15	-103	-87%	-19%
69	Prosser Bay	8			1990	_	_	34	_	_	
71	Maria I.	8, 9, 11	1946	1966	1990	358	1574	605	?	?	
73	Blackman Bay	7	1948		1990	1854	_	1648	-206	-11%	-3%
77	Port Arthur (Long Bay)	8	1946		1992	43	_	21	-22	-51%	-11%
78	Port Arthur (Carnarvon Bay)	8	1946		1992	104	_	68	-36	-35%	-8%
79	Wedge Bay & Parsons Bay	8	1946	1966	1992	87	117	46	-41	-47%	-10%
80-82	Sloping Main to Deer Pt.	8, 9		1966	1990	_	1739	861	-878	-50%	-21%
83-85	Deer Pt. to Chronicle Pt.	8		1966	1990	_	1266	796	-470	-37%	-15%
86/87	Chronicle Pt. to Fulham Pt.	8		1966	1990	_	1645	860	-785	-48%	-20%
88	Fulham Pt. to Primrose Pt.	8	1948		1990	5	_	1	-4	-80%	-19%
89	Primrose Pt. to Tiger Head	9	1948	1969	1991	18	_	7	-11	-61%	-14%
90/91	Pittwater	4	1948	1969	1990	1276	585	75	-1201	-94%	-22%
93	Pipe Clay Lagoon	7	1948		1992	30	_	0	-30	-100%	-23%
95	C. Direction to Gellibrand Pt.	9	1948	1969	1990	33	_	0	-33	-100%	-24%
96	Ralphs Bay (Mortimer Bay)	7	1948	1969	1990	398	303	0	-398	-100%	-24%
97	Ralphs Bay (Rokeby)	7	1948	1969	1990	32	46	0	-32	-100%	-24%
100	North West Bay	8	1948		1992	320	_	200	-120	-38%	-9%
101	Oyster Cove	8			1992	_	_	26	_	_	
102	Oyster Cove Pt. to Deadmans Pt.	8			1992	_	_	44	_	_	
103	Deadmans Pt. to Birchs Pt.	8			1990	_	_	23	_	_	
104	Birchs Pt. to Three Hut Pt.	8	1948	1965	1990	411	492	14	-397	-97%	-23%
109	Port Esperance	8			1992	_	_	30	_	_	
110	Hastings Bay & Southport	5, 8			1990	_	_	52	_	_	
111	Southport Lagoon	7			1992	_	_	637	_	_	
112	Recherche Bay	8			1991	_	_	11	_	_	
113	Dennes Pt. to Woodcutters Pt.	9			1985	_	_	0	_	_	
117	Missionary Bay	8			1985	_	_	4	_	_	
118	Great Bay	8			1985	_	_	61	_	_	
119	Isthmus Bay	8			1985	_	_	98	_	_	
122	Great Tayor Bay	8			1990	_	_	61	_	_	
124	Cloudy Lagoon	4		1965	1990	_	346	297	-49	-14%	-5%
146	Parrys Bay (Whitemark)	9			1991	_	_	2100	_	_	
147	Adelaide Bay (Lady Barron)	8			1991	_	_	2200	_	_	

6.1.1.2 Coastal areas with limited decline

The area including Greens Beach and the mouth of the Tamar (21 & 22) indicates a decline of 19% from 1946 to 1991. This is partly due to losses in the Kelso area due to the construction of a training wall for tidal flow in the river. Other losses are mainly in shallow water on the western shore north of Kelso where *Zostera muelleri* and *Posidonia australis* have declined (Map 6.1).

Blackman Bay (73) (Map 6.2) experienced loss of 11% from 1 854 to 1 648 ha between 1948 and 1990. This may be due to mapping errors, although *Z. muelleri* beds near the shack area of Marion Bay appear to have declined, and there is photographic evidence that beds in the bay near the Dunalley canal have receded from deeper water. A number of local users and residents believe that seagrasses are becoming more abundant at present, and an oyster grower has recognised a seven year cycle of growth and decline (I. Cleaver, pers. comm.).

Cloudy Lagoon (124) (Map 5.25) also indicates a marginal 14% decline between 1965 and 1992, although recent observations suggest that, like Blackman Bay, there is currently a significant regrowth of *Heterozostera tasmanica* in the lagoon (G. Edgar, pers. comm.).

6.1.1.3 Coastal areas where perceived gross change relates to poor aerial photograph quality

Whilst acknowledging the inherent difficulties in digitising aerial photographs generally, Maria Island posed particular problems due to different scales and photograph qualities. The differences in coverage between different years (see Table 6.1) can be largely accounted for in mapping offshore *Heterozostera tasmanica* beds in Mercury Passage, and the detail of seagrasses in Chinamans Bay. These were more clearly visible in the 1966 photographs. In general, the *H. tasmanica* and *Amphibolis antarctica* beds fringing the west coast of the island appear to have changed little, although there has been some decline in the more defined seagrass beds in Mercury Passsage between 1966 and 1990 (for 1990 extent see Map 5.15).

6.1.1.4 Coastal areas of significant decline

A number of areas revealed considerable losses of seagrass, and in some cases sampling found little evidence of their continuing presence.

Zone A: Duck Bay (3) (Map 6.3) shows a loss of 78% from 466 ha in 1968 to 104 ha in 1990. There was some difficulty with photo-interpretation in this case, but a significant decline in *Zostera muelleri* beds on the extensive intertidal flats is evident. This finding is largely supported by the observations of local oyster growers.

The North East Bay area of Port Sorell (19) (Map 6.4) shows a near total decline between 1946 and 1990, a loss of 69 ha of *Zostera muelleri*. A severe storm in 1953 stripped the *Zostera* beds off the sand flats, but this species became abundant again within 9 months (Thomson 1959). From the mid 1950s a local resident observed a steady decline during work with C.S.I.R.O. on the introduction of Pacific oysters in Port Sorell, which began in 1953. The seagrass was at times covered with filamentous algae (B. Griffith, pers. comm.). Some small patches of *Z. muelleri* remain in Little Bakers Creek, and there is photographic evidence of small *H. tasmanica* patches in deeper channels.

Zone B: Georges Bay near St. Helens (43) (Map 6.5) experienced a 48% decline from 295 ha to 153 ha between 1950 and 1992. Much of this decline has been in Moulting Bay, and on sandflats near the mouth.

Other areas in this section of the coast could not be mapped. The only significant area of seagrass habitat is Ansons Bay (38). This was sampled, and, anecdotally, there is local concern that the ecology of the Bay has been seriously impacted by increased shack development on the north shore. The impacts include a reduction in seagrasses. No aerial photographs could be found that revealed any submerged detail.

Zone C: Coles Bay (59) has lost approximately half its seagrass, whereas beds further from human development on the Freycinet Peninsula appear to have increased in area. Sampling revealed that beds of *Halophila australis, Heterozostera tasmanica* and *Amphibolis antarctica* were covered to some degree with algal epiphytes. The *H. australis* beds were very sparse.

H. tasmanica and Z. muelleri beds in Spring Bay (68) near Triabunna have declined from 1946 to 1991 (Map 6.6). Perhaps 103 ha of seagrass has been lost, leaving about 15 ha in shallower water on the eastern shore, and remnants elsewhere. A local fisherman speculated that the decline coincided with the operation of an alginate processing plant near the bay entrance in the 1950s. The adjacent Prosser Bay could only be mapped in the present period due to the poor quality of earlier aerial photographs.

Zone D: This zone, which covers the populous south east of the State, has experienced the most serious losses of seagrass. Although not all areas have been mapped over time, sampling observations, aerial photographic and anecdotal evidence indicate that only isolated areas such as Southport Lagoon (111) and Cloudy Lagoon (124) are unaffected.

Port Arthur (Map 6.7) indicates a decline of 51% from 43 ha to 21 ha in Long

Bay (77) between 1946 and 1992, and losses of 35% in the Carnarvon Bay area (78) from 104 ha to 68 ha over the same 46 year period.

Wedge Bay and Parsons Bay (79) near Nubeena on the Tasman Peninsula were mapped from aerial photographs taken in 1946, 1966 and 1992. Over the first twenty of these years, an increase is indicated from 87 to 117 ha, but subsequently seagrasses appear to have declined to 46 ha by 1992, a loss from 1946 coverage of 47% (Map 6.8). Most of this decline has occured in *H. tasmanica* beds in shallow water across of Wedge Bay, and in deeper parts of Parsons Bay.

Early photography was not suitable for seagrass identification in areas 80 to 87, which includes Sloping Main, and the shoreline of Norfolk Bay travelling anti-clockwise to Fulham Point near Dunalley. However, these areas were mapped from projects in 1966 and 1990, and although the deeper boundaries of the seagrass beds were very difficult to identify, there is evidence that significant losses have occured in shallow bays in most of this region (Map 6.2). In particular, the extensive beds off Sloping Main (80) and Dunalley Bay (86 & 87) appear to have declined by approximately half, losses calculated at 861 and 860 ha respectively. Heavy algal epiphyte loads were found in many parts of this area (see Section 6.2).

Pittwater (90 & 91) is one of a number of areas closer to Hobart that appear to have suffered massive losses of seagrass since the late 1940s (Map 6.9). Past references are few, though Harris (1968) collected *Z. muelleri* samples over a wide area, including many sites where the species does not now occur. The coverage calculated in ARC/INFO suggests a decline from 1201 ha in 1948 to 585 ha in 1969 and down to 75 ha in 1990, a 94% decrease over 45 years. There were some difficulties in photo-interpretation in this area, and the decline may not be so severe, but losses are in part corroborated by local knowledge (J. Prestige, pers. comm.), although the same observer has noted a small recovery in the summer of 1992/93. Significant environmental degradation is indicated by these results. The mouth of Pittwater in the area of Tiger Head, although a very small area, has also experienced a decrease in seagrasses from 18 ha in 1948 to 7 ha in 1991. A local resident recalls dense seagrass as far as the channel and off Spectacle Island in the 1950s. This has now largely disappeared D. Walter, pers. comm.).

References are made to the past presence of seagrasses in Pipe Clay Lagoon (93) by Guiler (1950a), and Woodward I.O. (1985), corroborated by an eye witness account by a local resident (anon.). No evidence could be found of seagrass in this tidal arm from beach searches or inspections of recent aerial photographs, although there may be small patches.

In Ralphs Bay (96 & 97) there are only a few living shoots of *Heterozostera tasmanica* near Lauderdale, and a very occasional dry sample on the southern shore of Ralphs Bay. Losses approaching 100% are indicated. From 1948 and 1969 aerial photographs, the beds in the southern part of the bay declined from 418 ha to 294 ha over 21 years (Map 6.10), and subsequently seagrasses died out, perhaps completely. A local resident described horseriding across the southern shore in the 1960s over long seagrasses in the shallows, and knee-high detritus on the beach (anon.). Similarly, in the northern bay to the west of Lauderdale seagrasses have diminished close to extinction. An increase between 1948 and 1969 from 32 ha to 46 ha was calculated, but these beds no longer exist (Map 6.11). It is assumed from present bathymetry that *Zostera muelleri* was the major species in 1948, with a belt of *Heterozostera tasmanica* near Lauderdale in deeper water, and patches elsewhere. Ralphs Bay was ideal seagrass habitat, and more extensive *H. tasmanica* beds may have existed earlier.

North West Bay (100) is surrounded by the rapidly developing residential, agricultural and light industrial area of Kingston, Margate and Snug. Sampling in the bay found areas of low density seagrass beds and high epiphyte loadings in many places (see Map 6.16). Seagrass beds were digitised from aerial photographs taken in 1948 and 1992. A loss of 120 ha from the original 320 ha was calculated, a reduction of 38% (Map 6.12). A local resident has noted a rapid decline in seagrasses on the eastern shore over the past 3 to 4 years, which he believes coincides with the establishment of a salmon farm at Powder Jetty (J. Keller, pers. comm.).

The western shore of the D'Entrecasteaux Channel from Birchs Point south to Three Hut Point (104) has broad shallows up to 1 km wide. Aerial photographs from 1948 and 1965 reveal dense beds of *Heterozostera tasmanica* covering the substratum the length of this area. Calculations of these beds in ARC/INFO show an increase over these 17 years from 411 ha to 492 ha. However, between 1965 and 1990 they declined to 14 ha, a decrease of 97% (Map 6.13). Sampling these shallows in 1992 showed a further shrinking of the beds. Historical records of the D'Entrecasteaux scallop fishery, and verbal accounts of two fishermen involved suggest that this area was not systematically dredged, save the occasional run.

6.1.1.5 Coastal areas not mapped

Other areas have not been mapped over time. Zone E sample areas are not suited to mapping from aerial remote sensing due to tannin levels in the water, and this also applies to the Huon River (107 & 108), Port Cygnet (106), to a lesser degree, Hastings Bay (110), and the northern part of Recherche Bay (112).

Some areas of the north east are similarly affected, and Ansons Bay (38) was excluded both because of lack of underwater visibility and very limited aerial photography coverage.

Some areas are consistently turbid, for example the upper Derwent (98), and the Tamar above Bell Bay (22) which were sampled but have no suitable aerial photography. Many small lagoons and river mouths were excluded because of their size, with seagrass beds well below 1 ha. With recent aerial photography having a scale of 1:42 000, mapping errors would overshadow the value of any data. Finally, some areas were not mapped through time limitations.

Two separate reports from the public relate to areas not mapped. Seagrass detritus washed up on Pardoe Beach to the east of Devonport (18), and similarly in Little Taylor Bay on Bruny Island (121) have reduced in volume considerably in the past decade. These areas were both sampled.

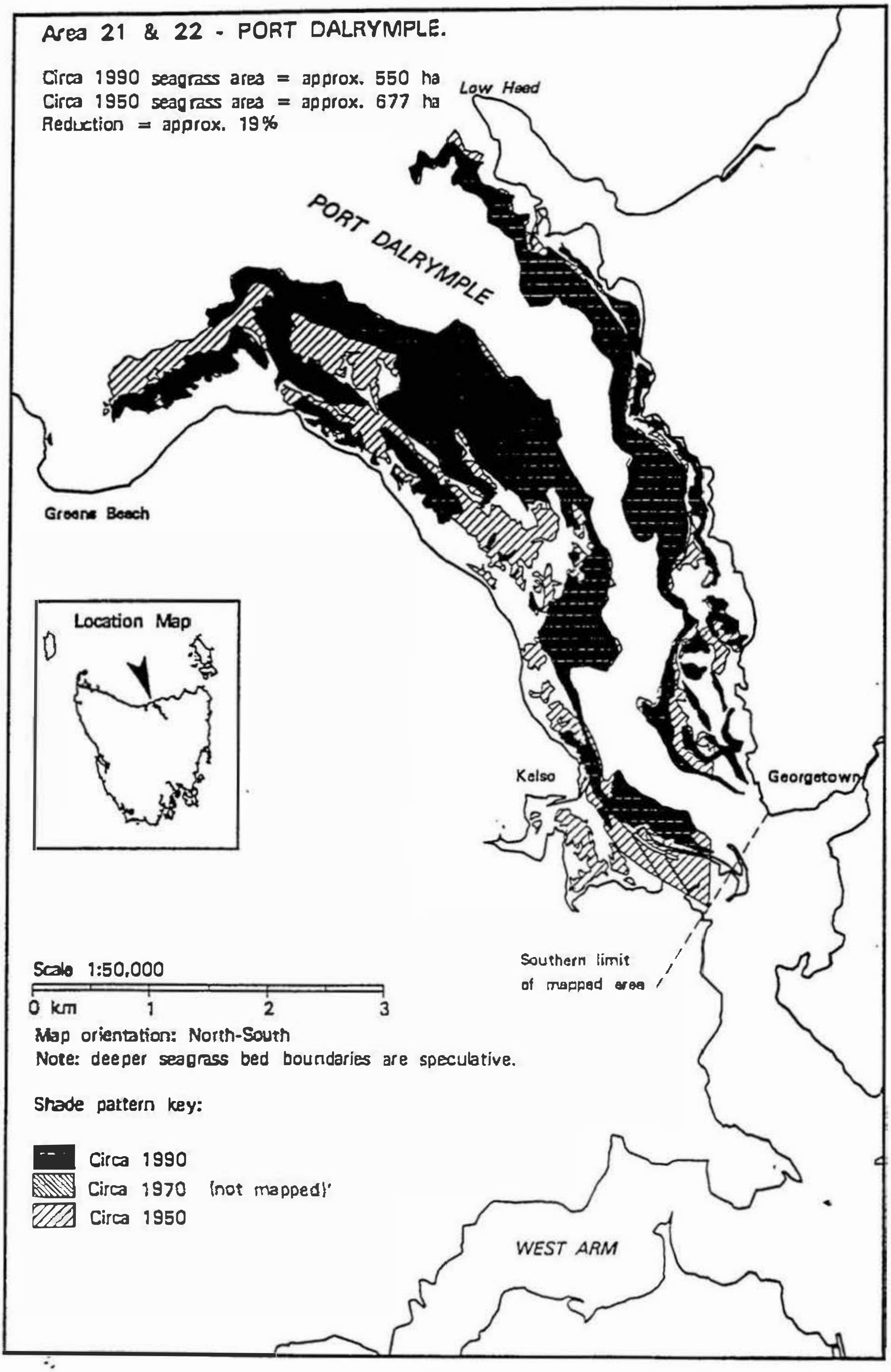
6.1.2 Overview of seagrass changes in Tasmania

The findings discussed and illustrated above reveal that, although seagrass communities in some parts of the State have remained apparently undisturbed by human activity or other agents, there have been some serious cases of decline. These have occurred throughout the State, but are all in close proximity to human centres of population, industrial or agricultural activity.

Sheltered and semi-sheltered bays, and shallow offshore areas flushed with water of oceanic origin have declined little, if at all. This includes the extensive *Posidonia australis* beds in the north west and those in the Furneaux Group, although, as discussed later, there is evidence of algal epiphyte growth near Whitemark and Lady Barron. Similarly, tidal lagoons and arms inundated with oceanic water have remained relatively pristine throughout the State where human development remains minimal. These include West and East Inlets near Stanley, Little Mussel Roe and Mussel Roe Lagoons in the north east, Moulting Lagoon, Little Swanport and Blackman Bay on the east coast, and Southport Lagoon and Cloudy Lagoon in the south east.

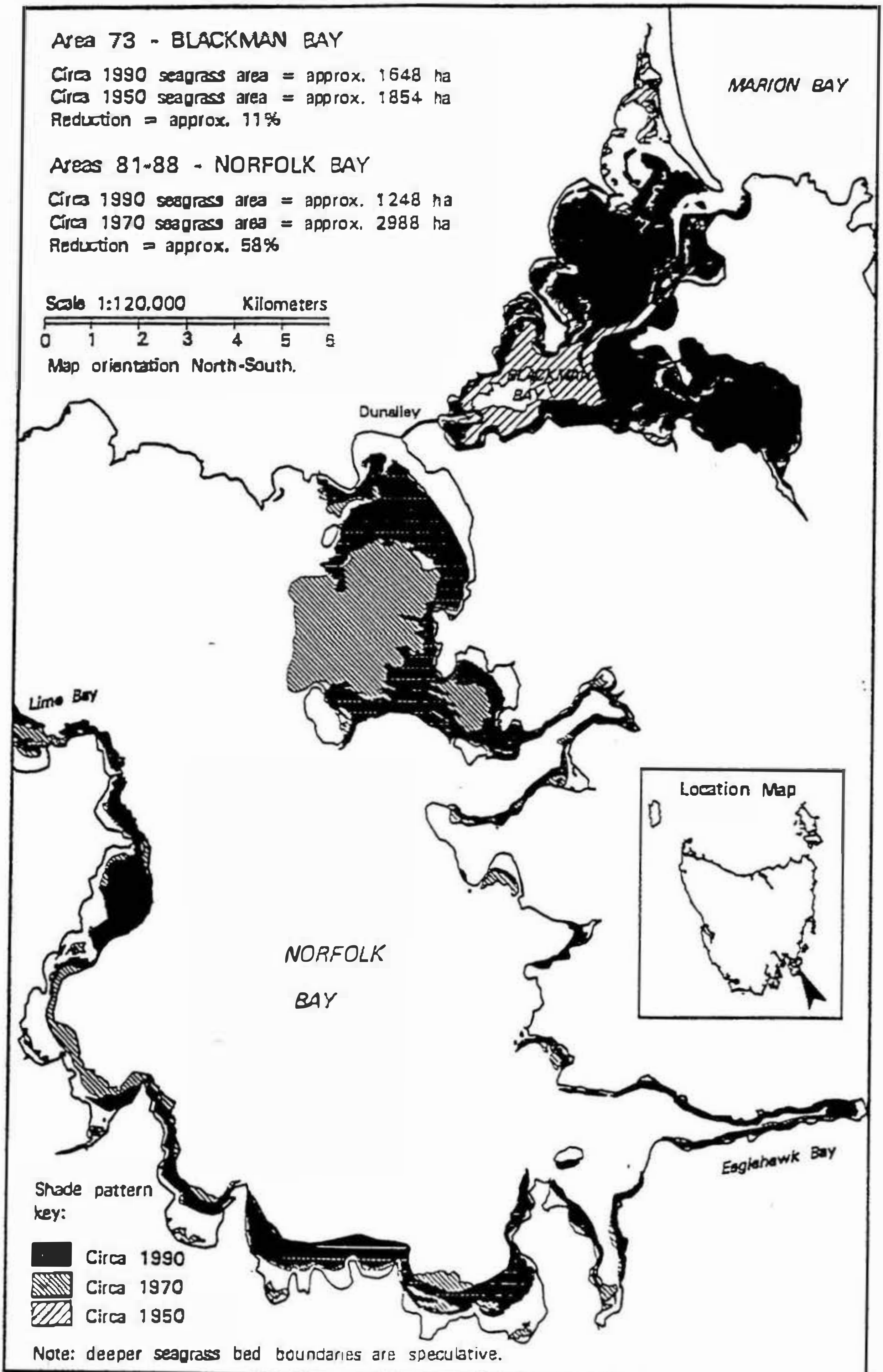
Open drainage systems, estuaries, straits and channels receiving effluent and runoff from human development, directly or indirectly, have experienced seagrass decline. This includes Duck Bay, Port Sorell and the Tamar on the north coast, Georges Bay and Spring Bay on the east coast, and most of the sheltered areas in and around Norfolk Bay, Frederick Henry Bay, the Derwent Estuary and the D'Entrecasteaux Channel.

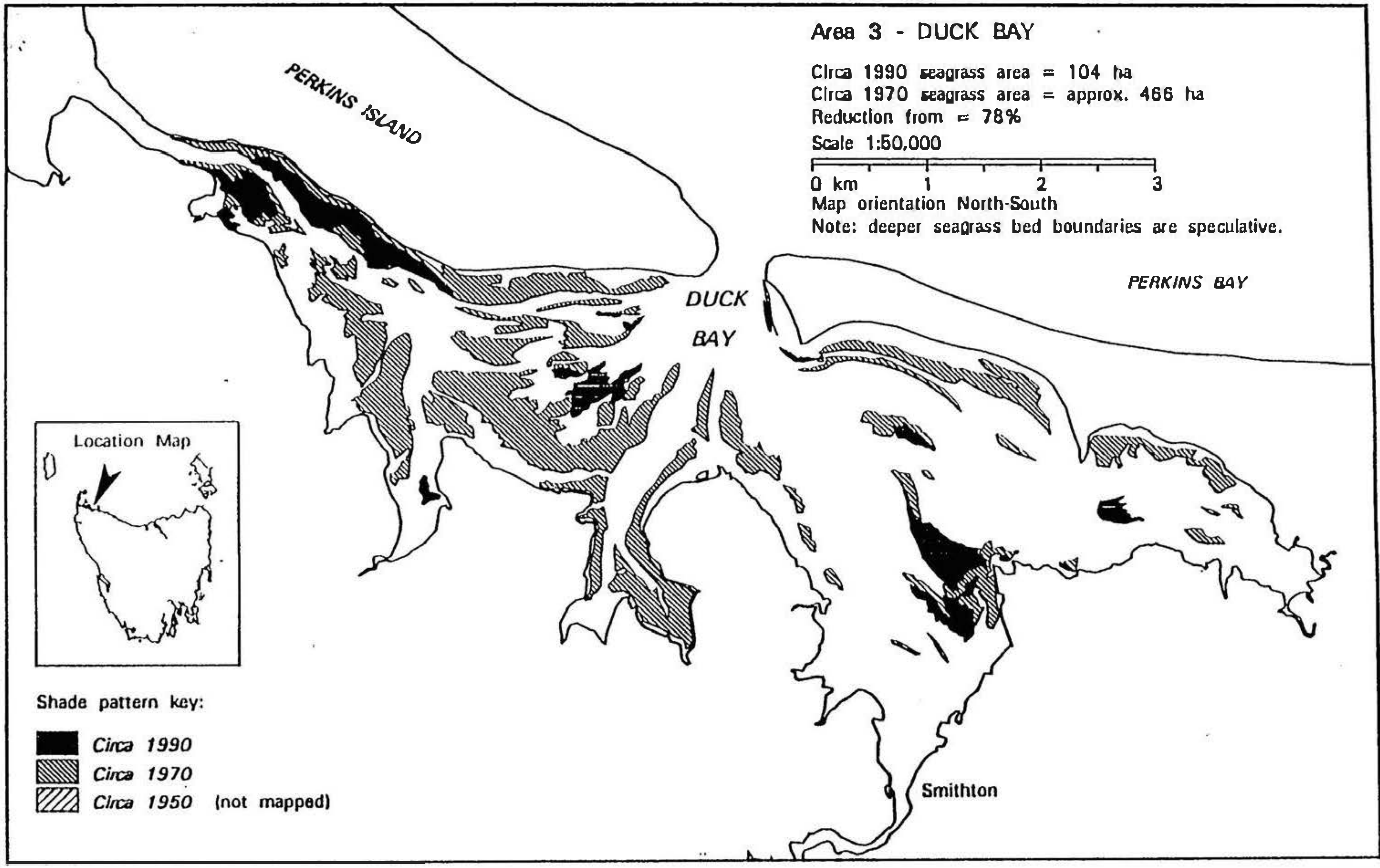
Map 6.1:
Seagrass decline in Port Dalrymple (Tamar Estuary)



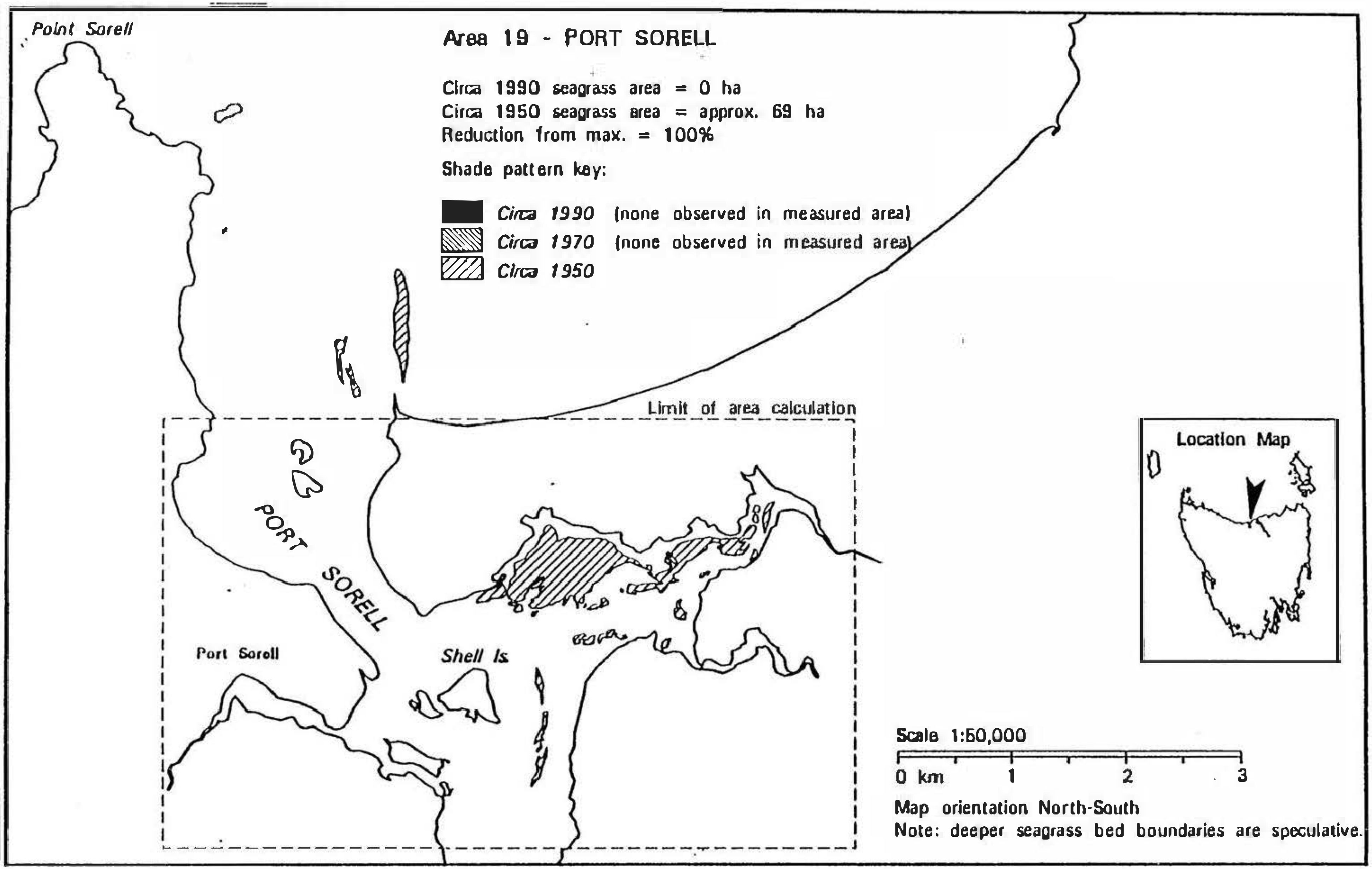
Map 6.2:

Seagrass decline in Norfolk Bay and Blackman Bay

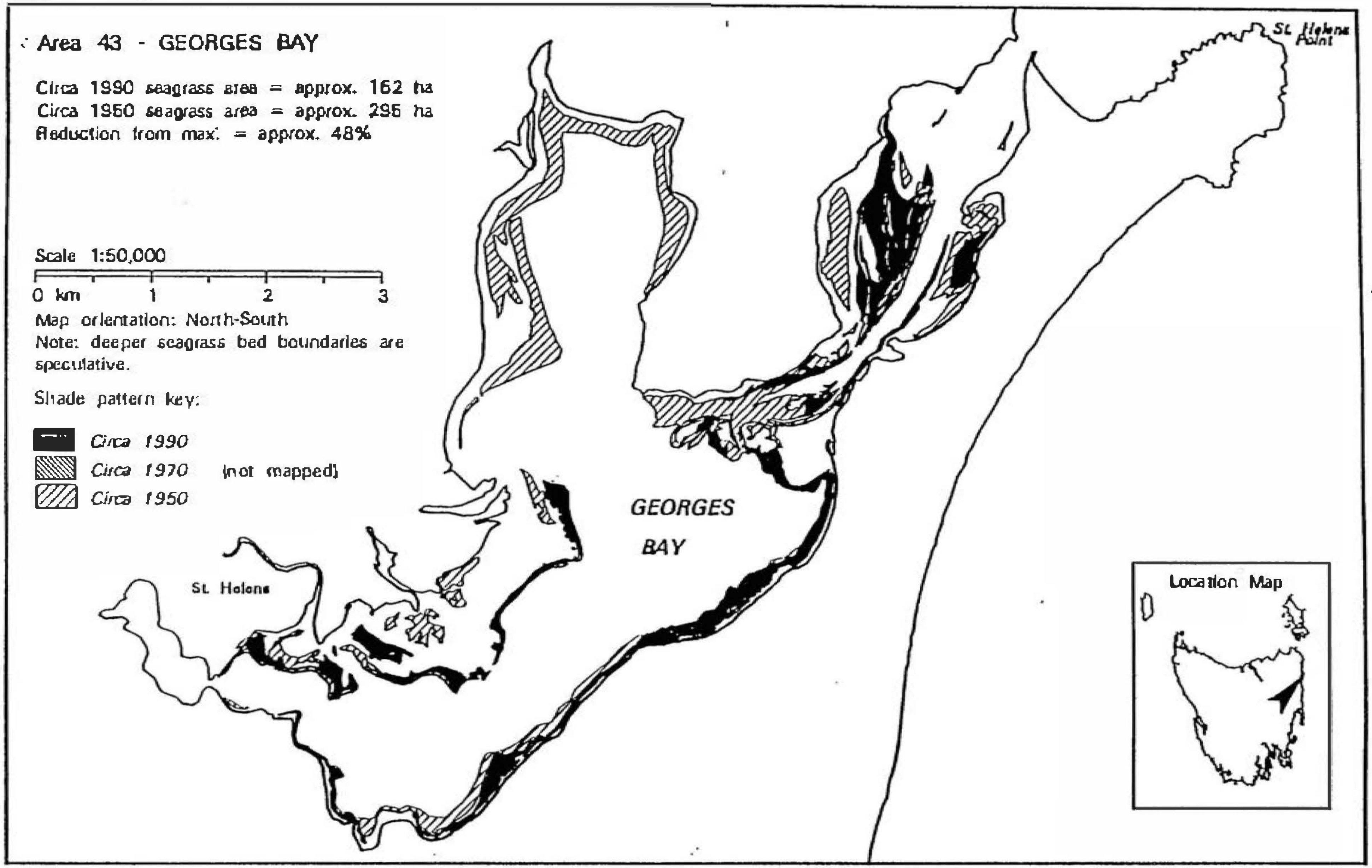




Map 6.3: Seagrass decline in Duck Bay

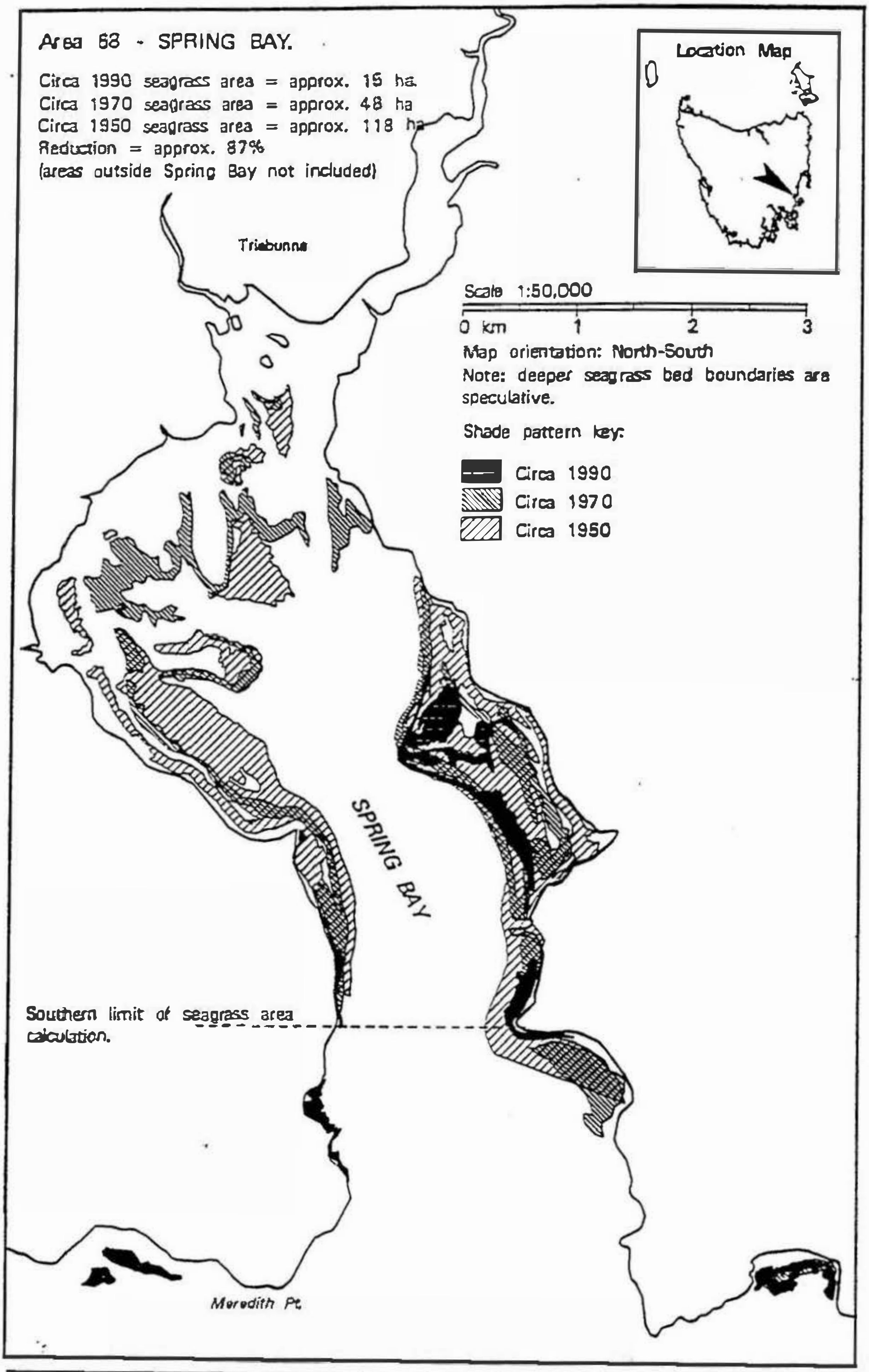


Map 6.4: Seagrass decline in Port Sorell

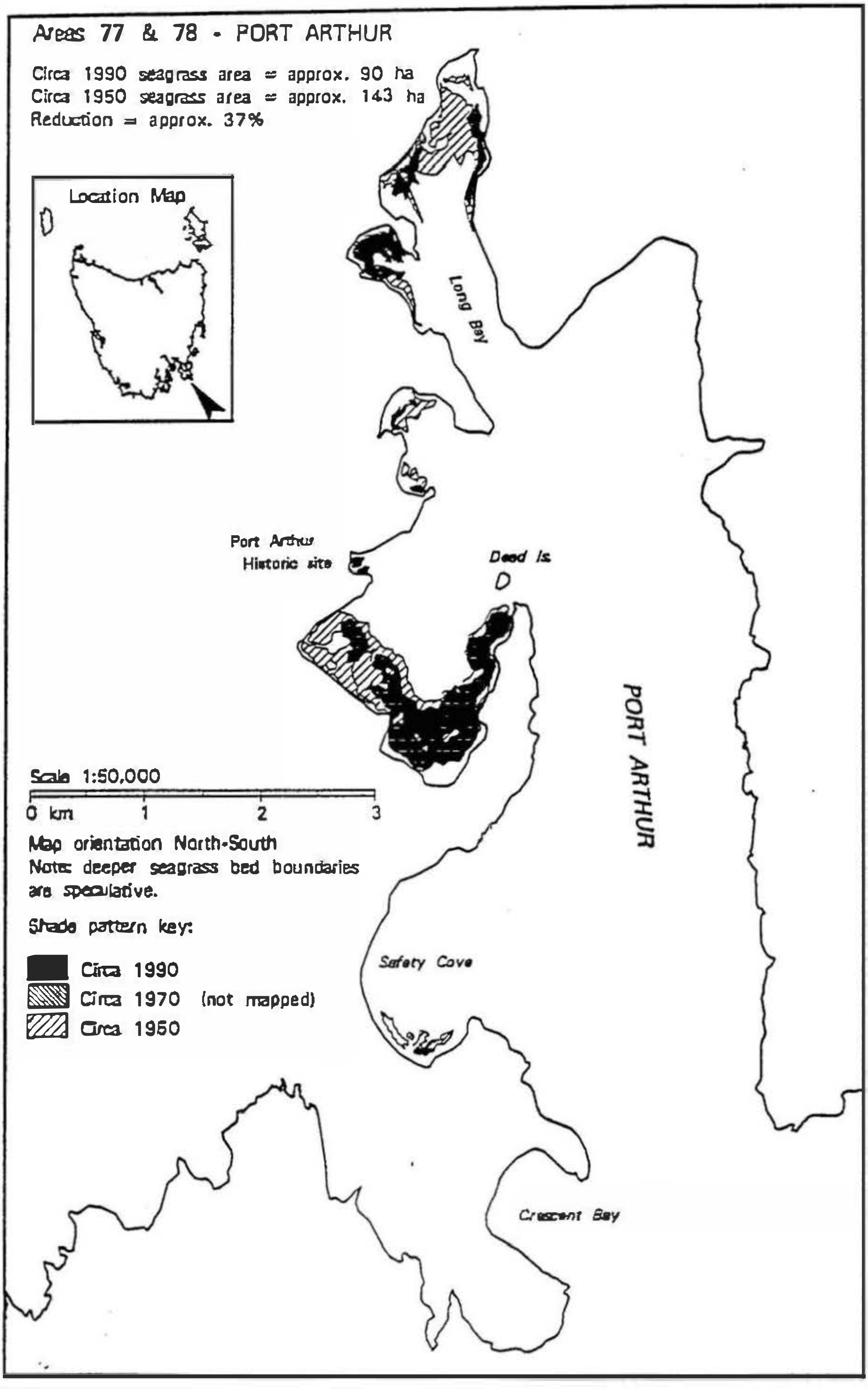


Map 6.5: Seagrass decline in Georges Bay

Map 6.6:
Seagrass decline in Spring Bay

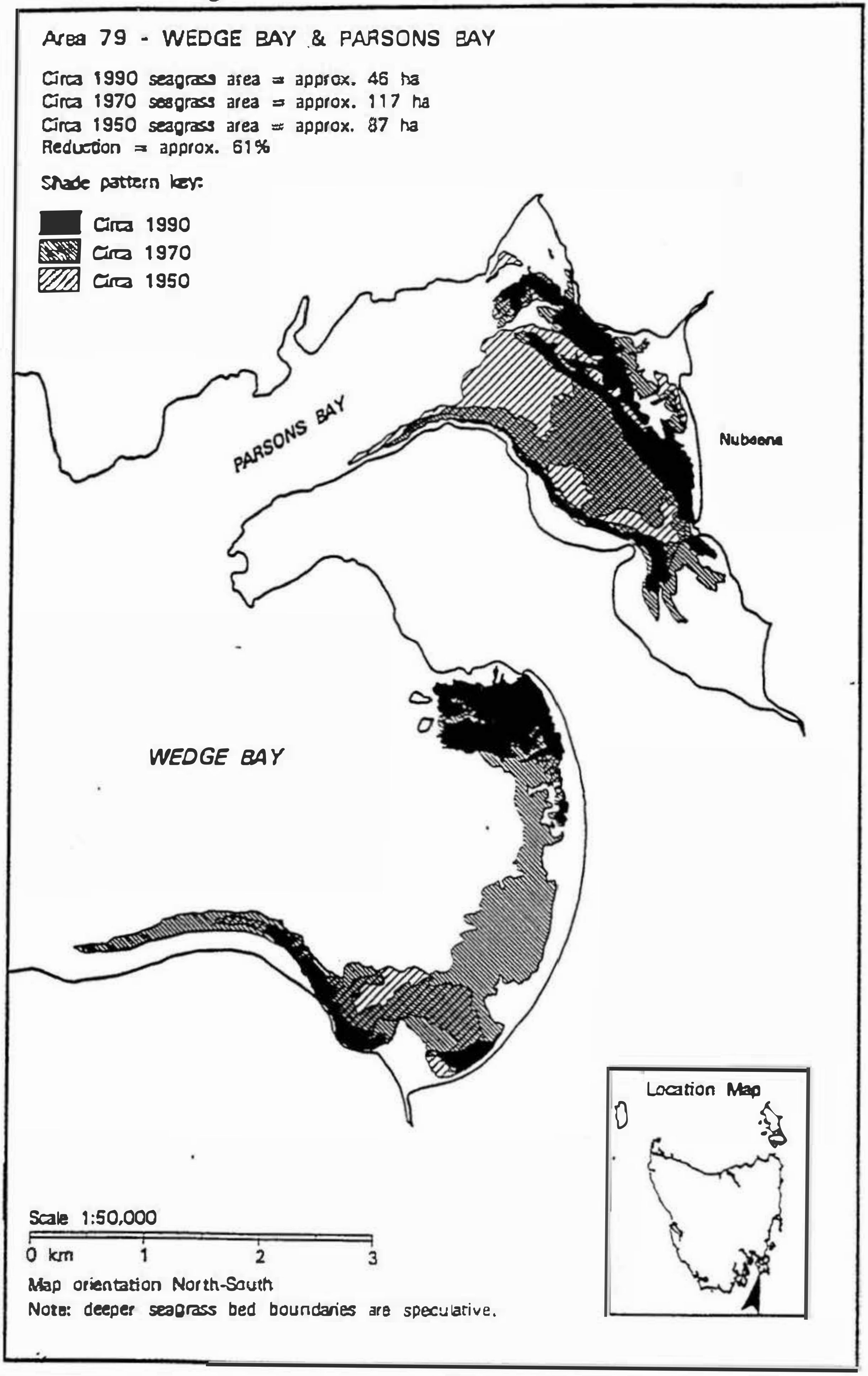


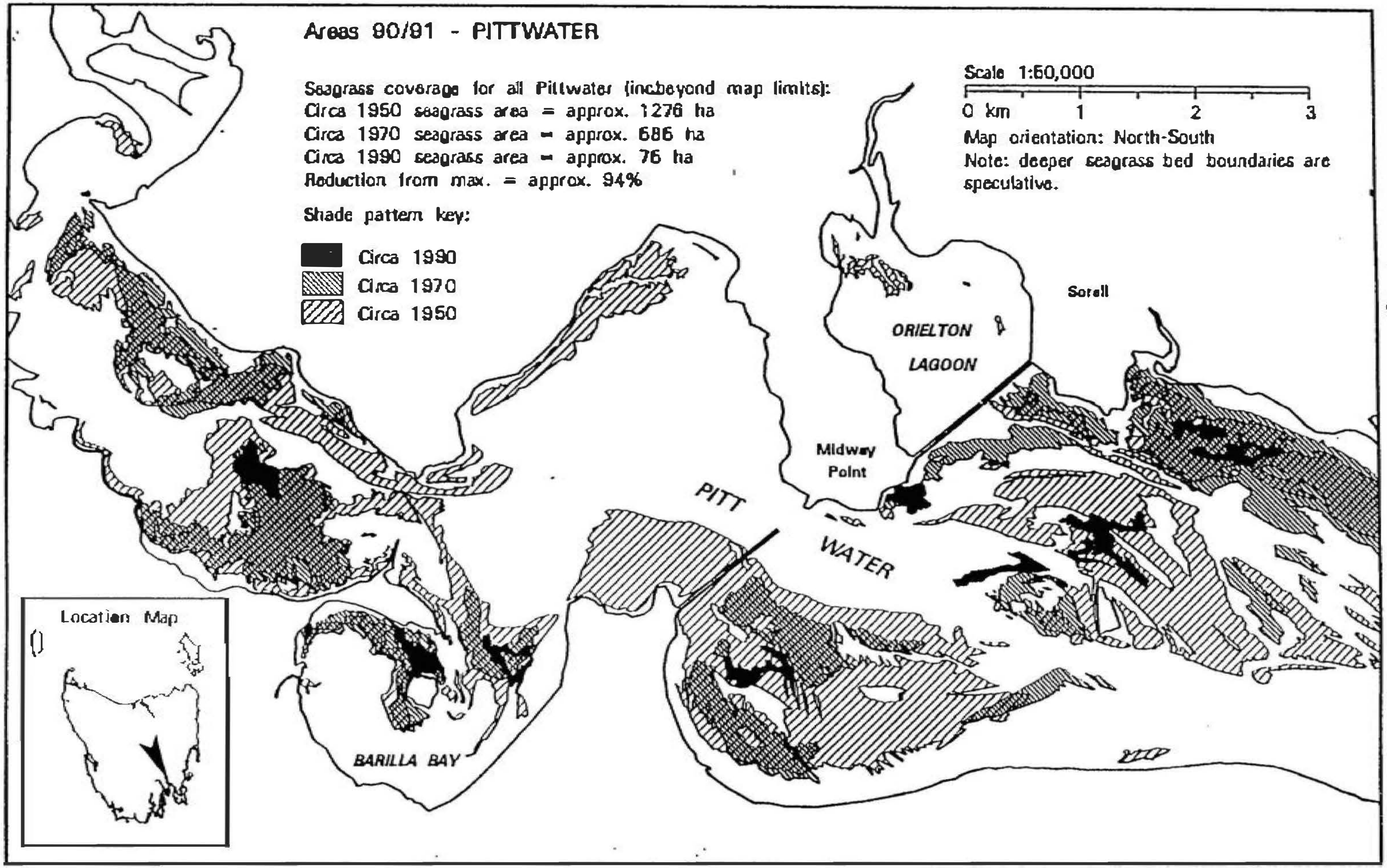
Map 6.7:
Seagrass decline in Port Arthur



Map 6.8:

Seagrass decline in Wedge Bay and Parsons Bay

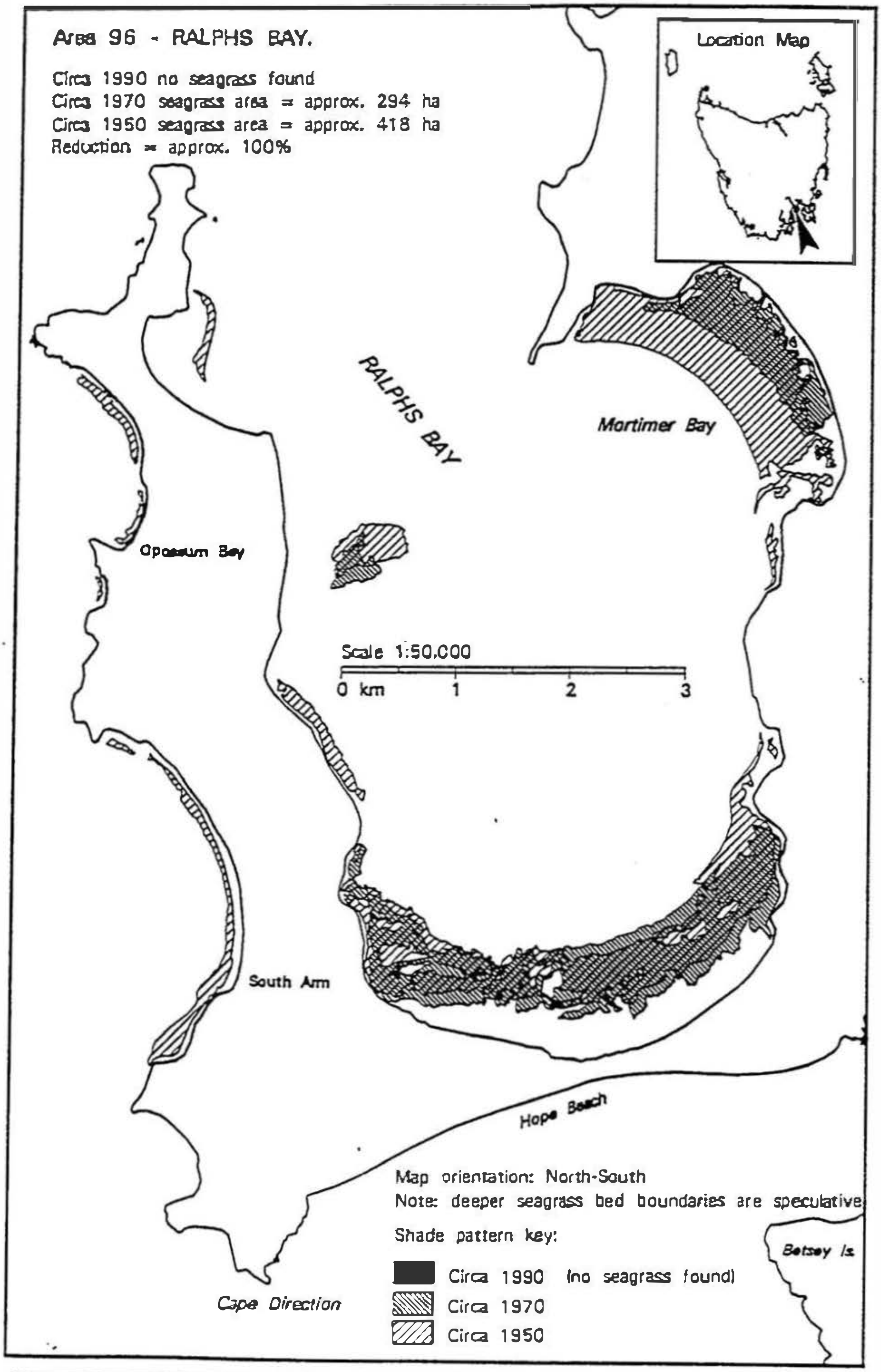




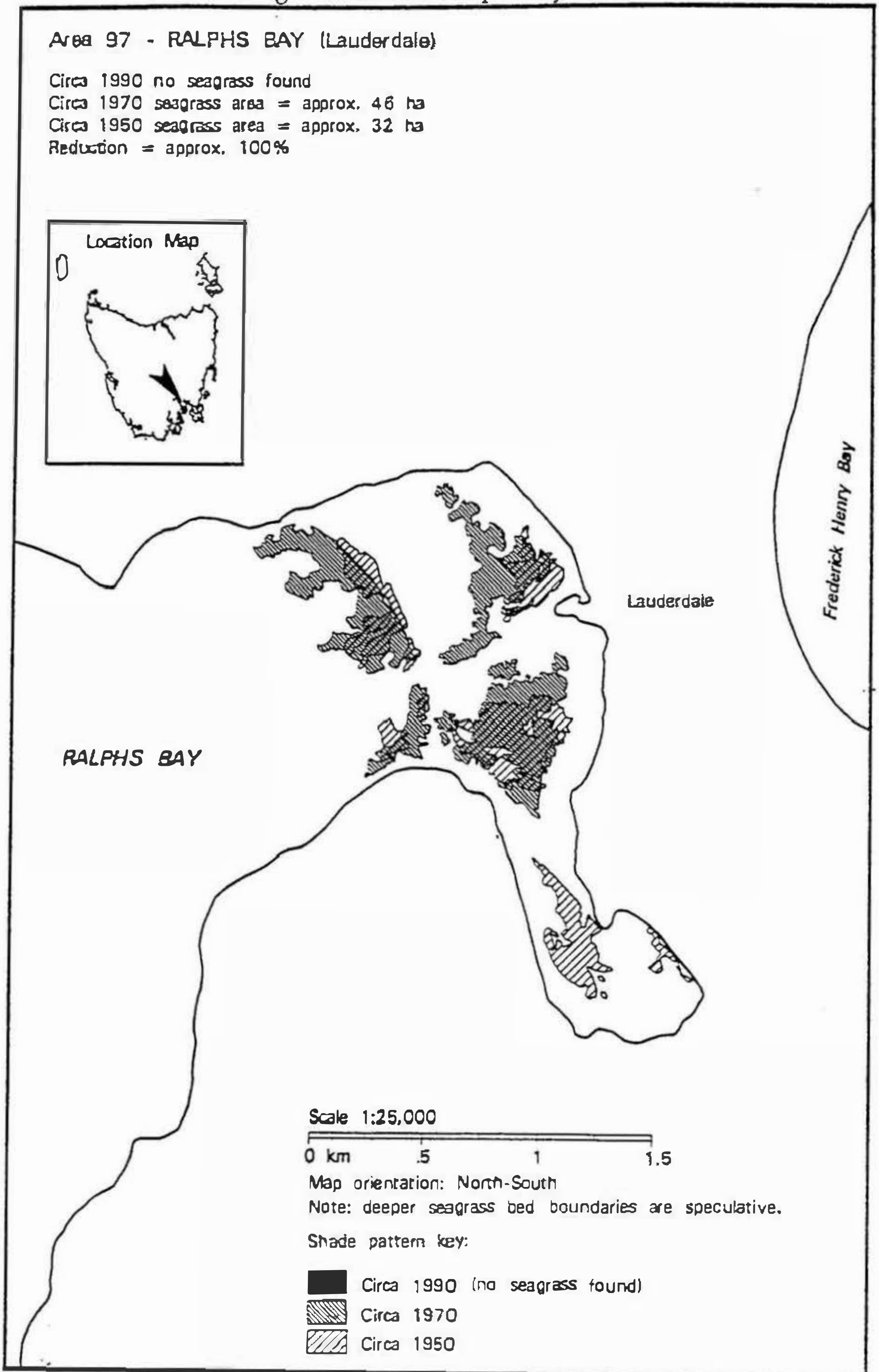
Map 6.9: Seagrass decline in Pittwater

Map 6.10:

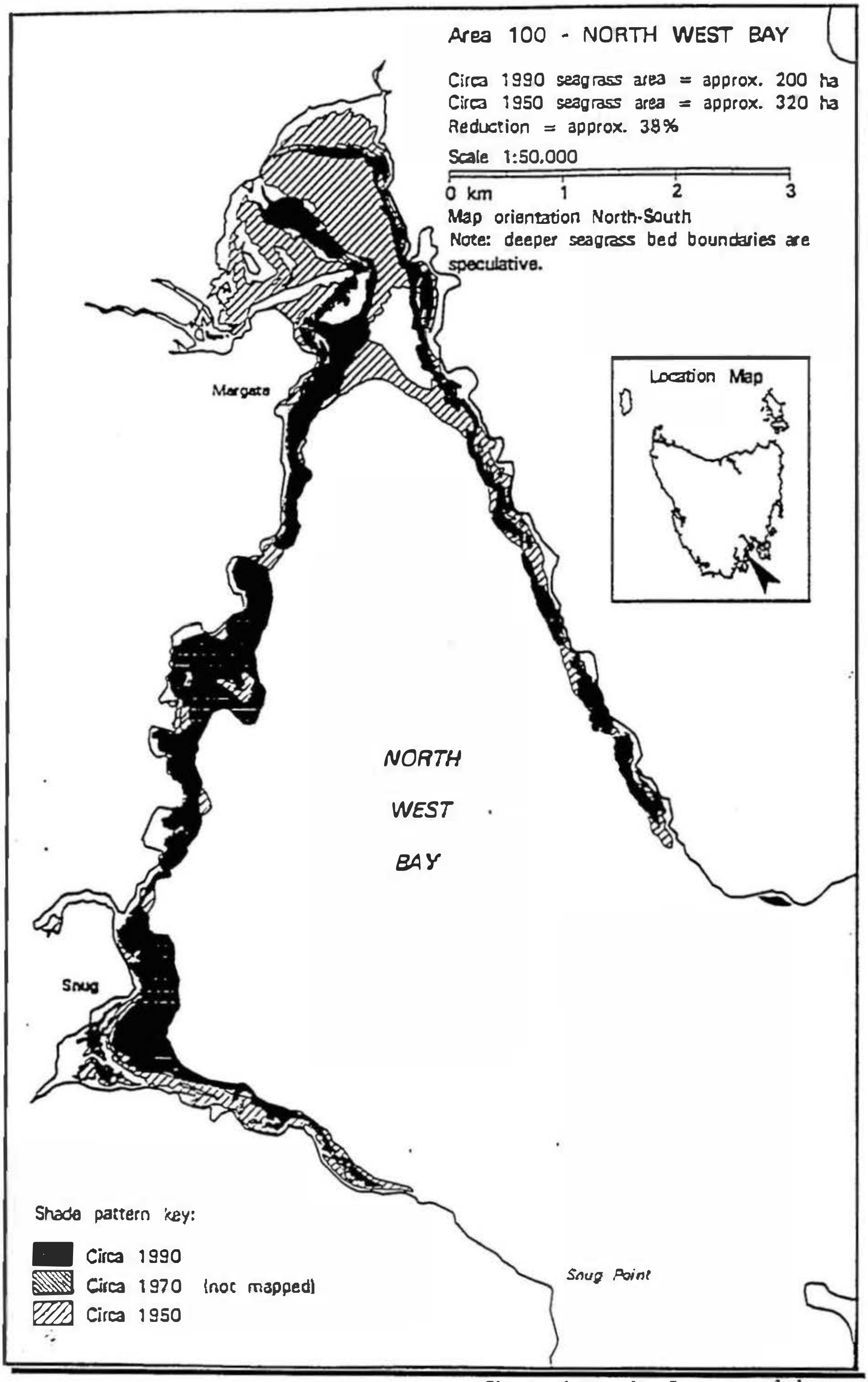
Seagrass decline in Ralphs Bay (south)



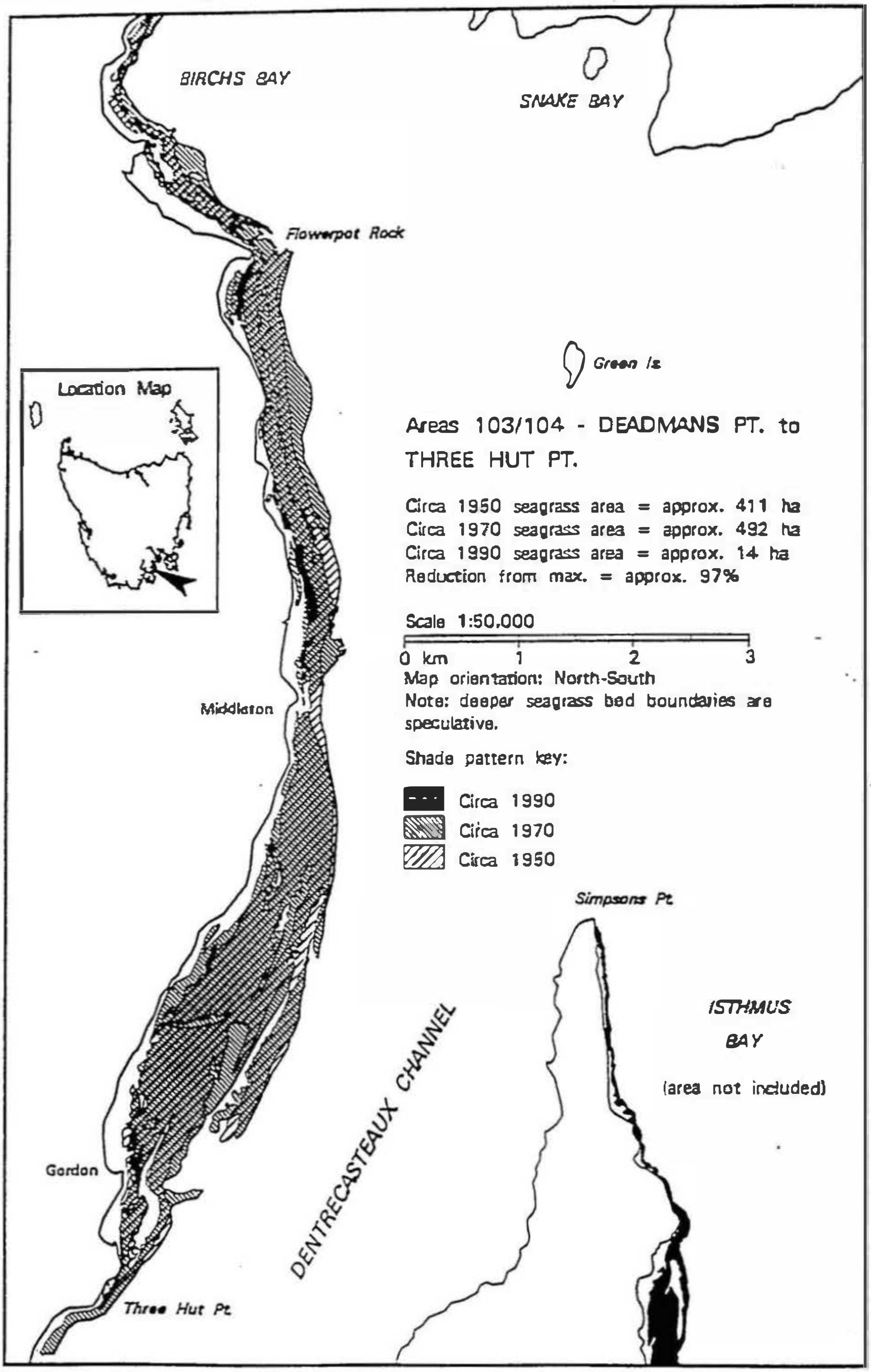
Map 6.11:
Seagrass decline in Ralphs Bay (north)



Map 6.12:
Seagrass decline in North West Bay



Map 6.13:
Seagrass decline in the D'Entrecasteaux Channel



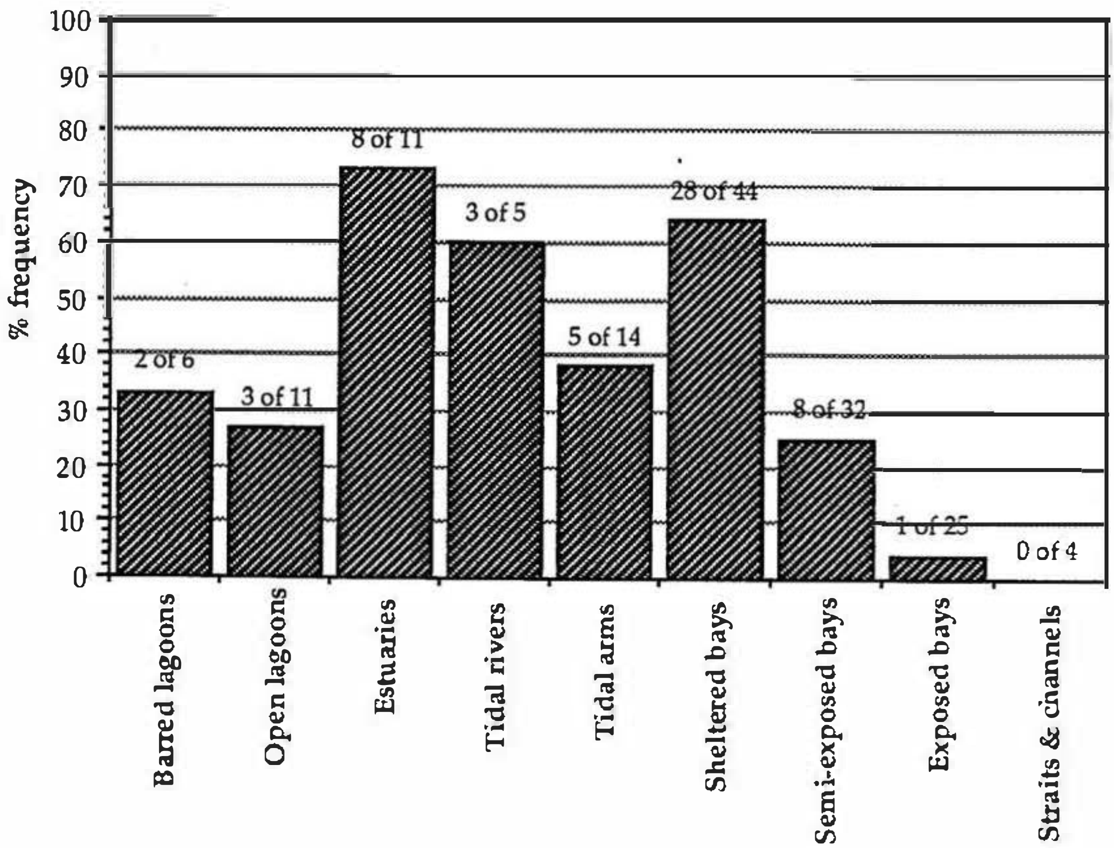
6.2 Algal epiphytes

6.2.1 Occurrence of algal epiphytes on seagrass beds

As described in section 4.2.6, each sample was assessed for evidence of algal epiphyte growth on a four point scale (none = 0; present = 1; heavy = 2; complete blanketing = 3). The relationship between algal epiphytes and seagrass decline is discussed in section 1.4.2. The incidence of samples with epiphyte values greater than 0 around the Tasmanian coast is shown on maps 6.14 (north west Tasmania), 6.15 (north east Tasmania), 6.16 (south east Tasmania), and 6.18 (Port Davey/Bathurst Harbour). Map 6.17 illustrates a subset of more heavily epiphytised samples in the south east.

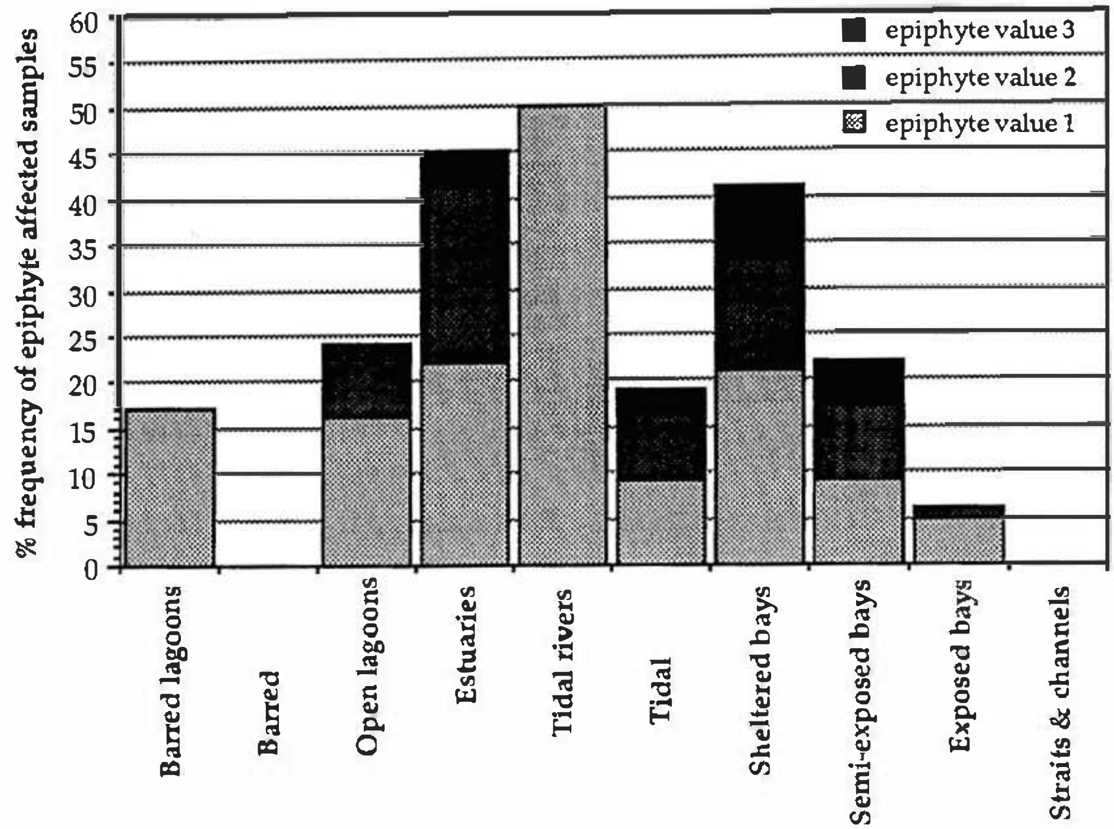
The percentage of sample areas of each coastal type where samples were found with epiphyte loadings is illustrated in figure 6.1. This graph shows that estuaries, tidal rivers and sheltered bays are particularly affected by algal epiphytes. Bar or beach dammed rivers have not been included. Only one was sampled, and this site (Scamander River) showed no evidence of algal epiphytes at that time.

Figure 6.1:
Frequency of epiphyte affected sample areas compared with total sample areas for each coast type



The frequency of samples with algal epiphytes in different coastal types further illustrates the tendency for seagrasses to be most frequently affected in estuarine habitats and sheltered bays (see Figure 6.2).

Figure 6.2:
Frequency of algal epiphyte affected samples in different coast types



The incidence of epiphytised samples in broad regions of the coastline is discussed below.

6.2.1.1 North west Tasmania

Algal epiphytes were recorded in only three coastal areas in this region, although not all areas were sampled. No values of 3 were recorded (Map 6.14). Those epiphytes found corresponded with areas of measured seagrass decline, or, in the case of Devonport (18), with an area of industrial, agricultural and residential development where seagrass decline has been noted by a local resident. On the evidence drawn from the case studies discussed in Chapter 1, the presence of algal epiphytes suggests that decline may be in progress in these areas. Frequent algal epiphyte loadings of 1 and 2 on *Posidonia australis* beds in the Tamar (22) are of particular concern, due to the poor ability to re-establish that this and other species of the genus have shown elsewhere in Australia.

6.2.1.2 North east Tasmania

This region includes the Furneaux Group, where samples from both Parrys Bay (146) and Adelaide Bay (147) had high algal epiphyte loadings. Off Whitemark, epiphytes values were higher near the airport and town, following a trend moving inshore of sparser *Posidonia australis* beds with shorter leaves. Two epiphyte values of 3 were found. One at a yacht anchorage near Bluff Farm, and the other off the mouth of Pats River.

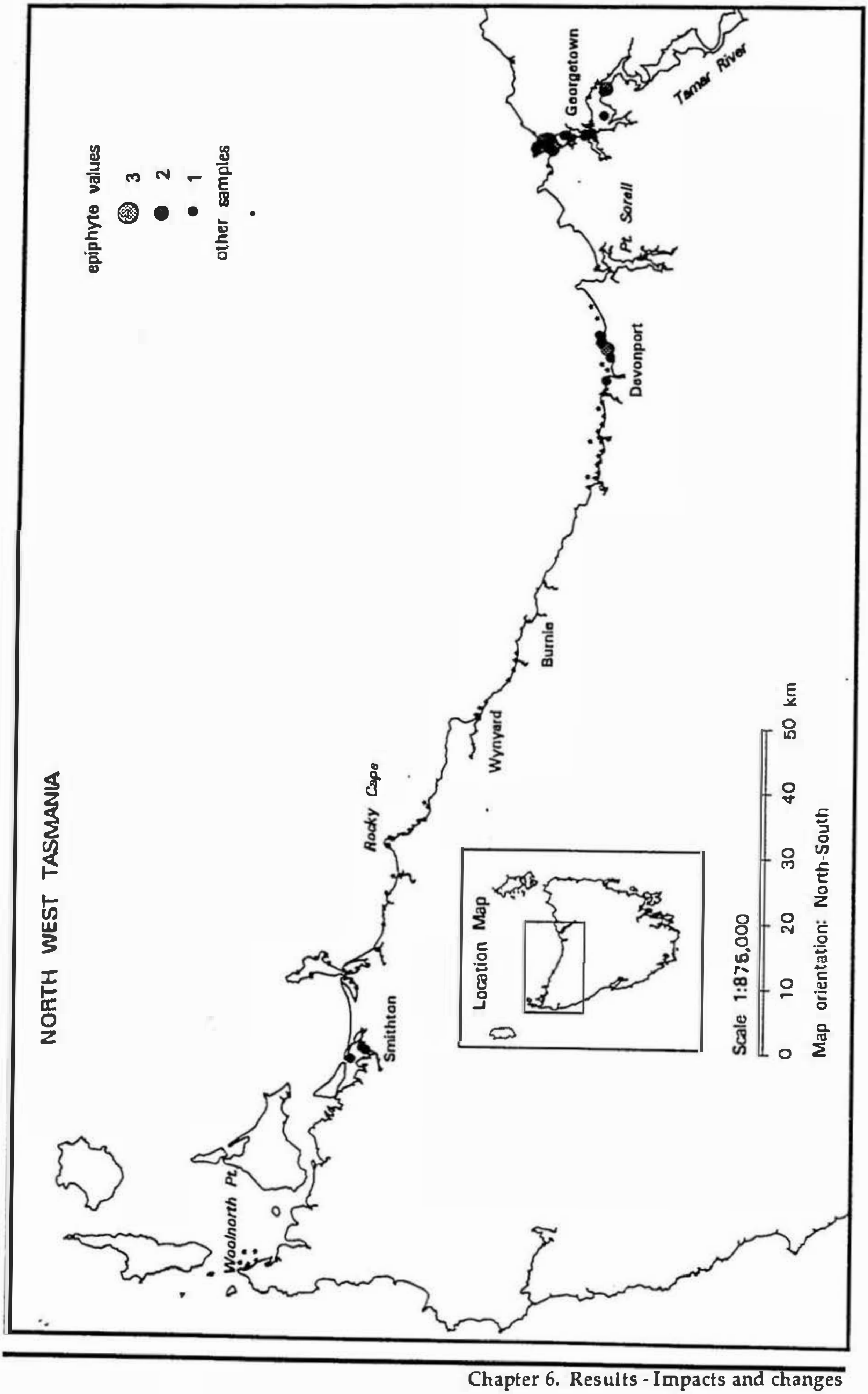
In Adelaide Bay off Lady Barron, an increasing epiphyte load occured in samples moving from the south west of the bay towards the town. Algal epiphytes were also heavy and the seagrass sparse along the town foreshore. In common with the Tamar, the high epiphyte coverage on *P. australis* beds in Parrys Bay and Adelaide Bay is of concern.

On the north east coast, levels of 1 and 2 were found in Ansons Bay and Georges Bay, and recordings of 1 at Wrinklers Lagoon, Hendersons Lagoon and Four Mile Creek. Seagrass decline in Georges Bay has been described earlier, and local reports of decline in Ansons bay also noted.

A St. Helens fisherman commented that mussel beds in Ansons Bay have in recent years become covered in 'green slime'. Hendersons Lagoon appears to be good *Zostera muelleri* habitat, but the mudflats over much of the lagoon are home to a dense population of burrowing crabs, and *Z. muelleri* was only found in the upper reaches with an algal epiphyte value of 1. No records of earlier coverage could be found.

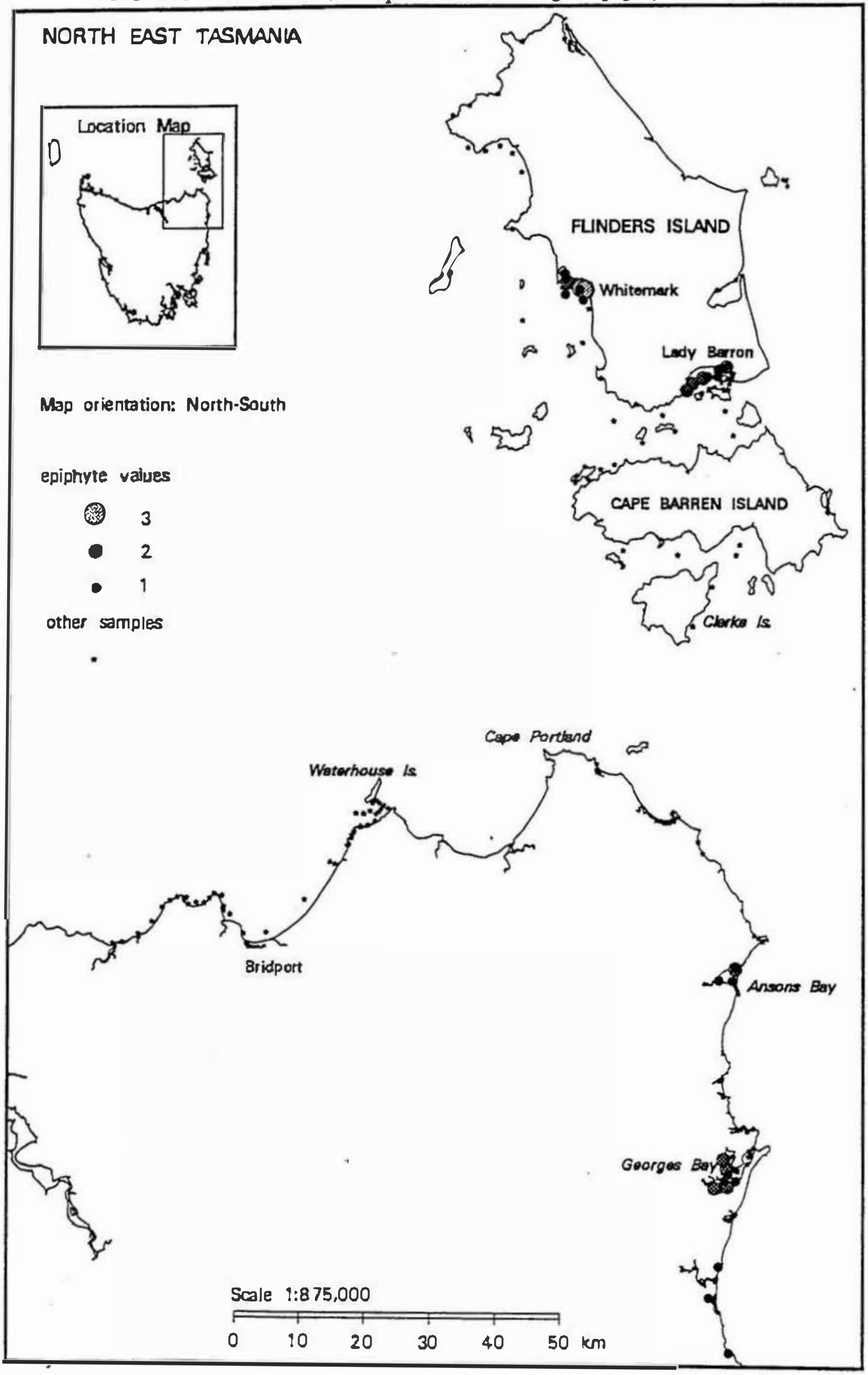
(Maps 6.14 and 6.15 follow)

Map 6.14:
North west Tasmania, sample sites with algal epiphyte cover



Map 6.15:

North east Tasmania, sample sites with algal epiphyte cover



6.2.1.3 South east Tasmania

Sampling in this region found dense clusters of algal epiphyte values in the 1 to 3 range (Map 6.16). Many sites are in areas already described as having suffered significant decline in seagrass cover in recent decades. These include Coles Bay (59), Spring Bay (68), Port Arthur (77 & 78), Parsons Bay and Wedge Bay (79), Sloping Main (80), Norfolk Bay and Frederick Henry Bay (81 to 89), upper Pittwater (90), North West Bay (100), the D'Entrecasteaux Channel (101 to 104, 118, 119 & 122), Port Esperance (109) and Hastings Bay and Southport (110).

Areas not mapped for seagrass change but showing high algal epiphyte values include the upper Derwent estuary (97), the D'Entrecasteaux coast of North Bruny Island from Dennes Point to Missionary Bay (113 to 117), Little Taylor Bay (121), Port Cygnet (106), the Huon River (107 & 108) and the north of Recherche Bay (112). These all had algal epiphyte values of 2 and in many cases 3, suggesting a threat to seagrass health at these sites.

Three areas, namely Little Swanport (65), Maria Island (71) and Blackman Bay (73) require further comment.

At Little Swanport the *Zostera muelleri* beds are abundant and dense. Much of the lengthy leaf shoots, particularly the lower parts, were found to support a dense algal epiphyte growth, particularly in proximity to the extensive intertidal oyster racks. However, there only appears to be dieback of seagrass directly under the racks, where light is excluded (The oyster farm managers rotate racks to allow recovery of the seagrass). One hypothesis poses that due to the regular tidal flushing of the lagoon with marine water from Great Oyster Bay, the majority of nutrient rich faecal matter from the oysters is removed, but enough remains to support not only the algal epiphytes, but also lush *Zostera muelleri* growth. Some weather conditions also strip epiphytes from the seagrass. A complex dynamic equilibrium is thus maintained. This notion is supported by studies on eutrophication (OECD 1982) indicating that low residence times of nutrients in water bodies reduces their eutrophic impact.

A similar situation may apply near oyster racks close to the Marion Narrows entrance to Blackman Bay where an algal epiphyte value of 3 was recorded. However, high values elsewhere in the bay are of more concern, since the flushing by clean oceanic water is not present.

Algal epiphytes off Maria Island from Return Point to Darlington were of a different nature, although values were consistently high. The epiphytes here were not the fine undifferentiated filamentous algae found elsewhere, but were a reddish-brown species, with a thicker branched form. This alga in places formed a dense mat through which sparse *Heterozostera tasmanica* leaf blades protruded. At some sites the *H. tasmanica* was more common. This area lies within the Maria Island marine reserve, and has recently been thoroughly surveyed in a flora and fauna baseline monitoring program, although results have not yet been published. The same or a similar species of red alga covers parts of the floor of Mercury Passage (N. Barrett, pers. comm.). Of more danger to seagrasses in the area is the introduced Japanese macroalga *Undaria pinnatifida*, which has rapidly increased its range since its introduction probably in 1982. Although an annual plant, the species can grow to 2 m, and in places covers 100% of the substratum (Sanderson & Barrett 1989).

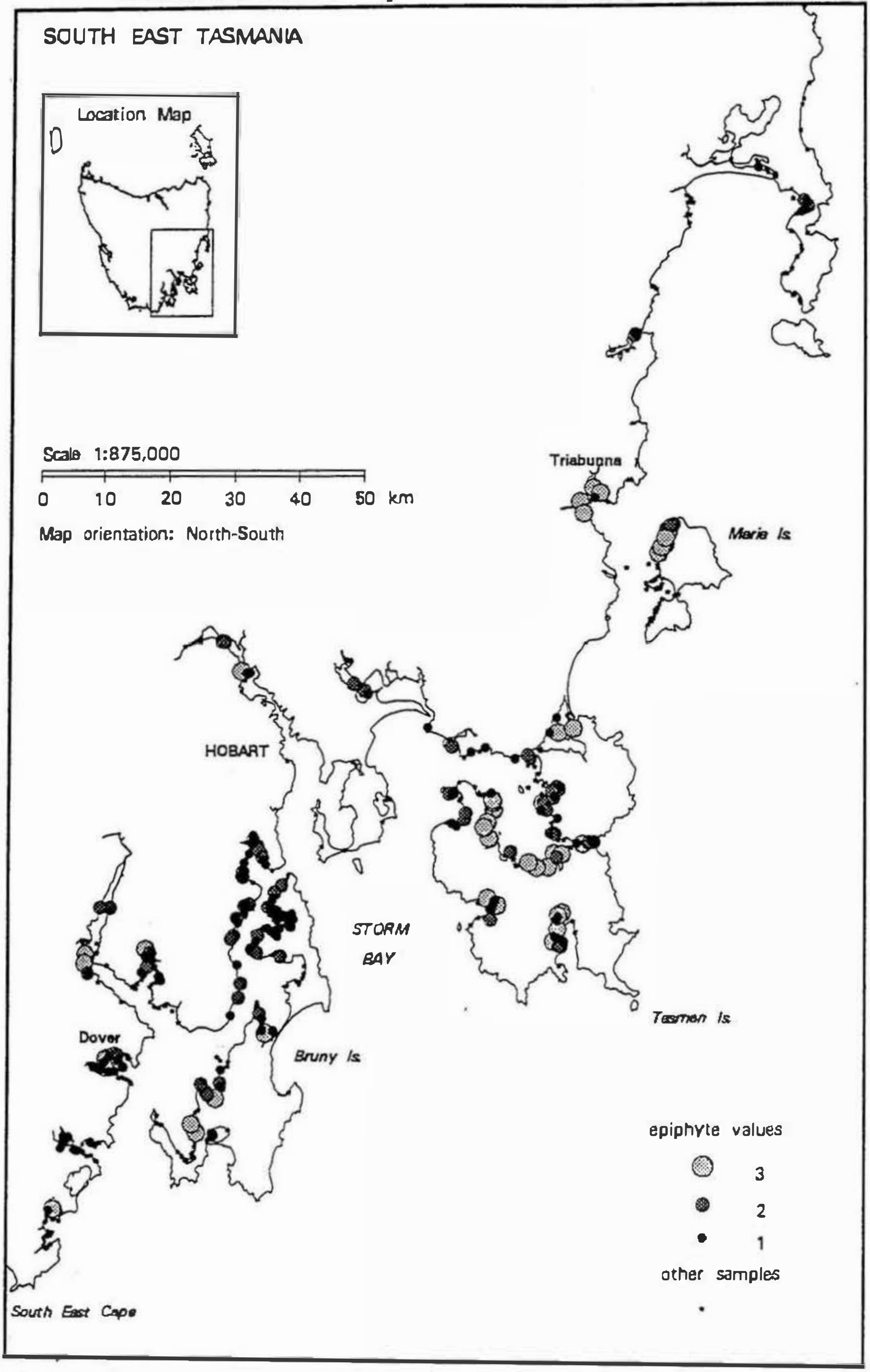
As with Map 6.16, Map 6.17 also indicates samples in the south east region with algal epiphyte values. However in this case samples with the higher values of 2 and 3 have been mapped where they correspond with a seagrass bed density of less than 40% cover. All algal epiphyte values of 1 have been excluded, and some areas are therefore no longer represented despite low seagrass density. Areas with algal epiphyte values of 2 and 3 no longer featuring in this subset due to high seagrass density include Little Swanport, Blackman Bay, the upper Derwent, Franklin on the Huon River, King George Sound in Norfolk Bay, and some sites in the D'Entrecasteaux Channel.

If it is assumed from their low density that the remaining beds are in a state of decline, then the coincident high algal epiphyte levels might indicate that these are the sites in which seagrasses are more threatened than elsewhere.

(Maps 6.16, 6.17 and 6.18 follow)

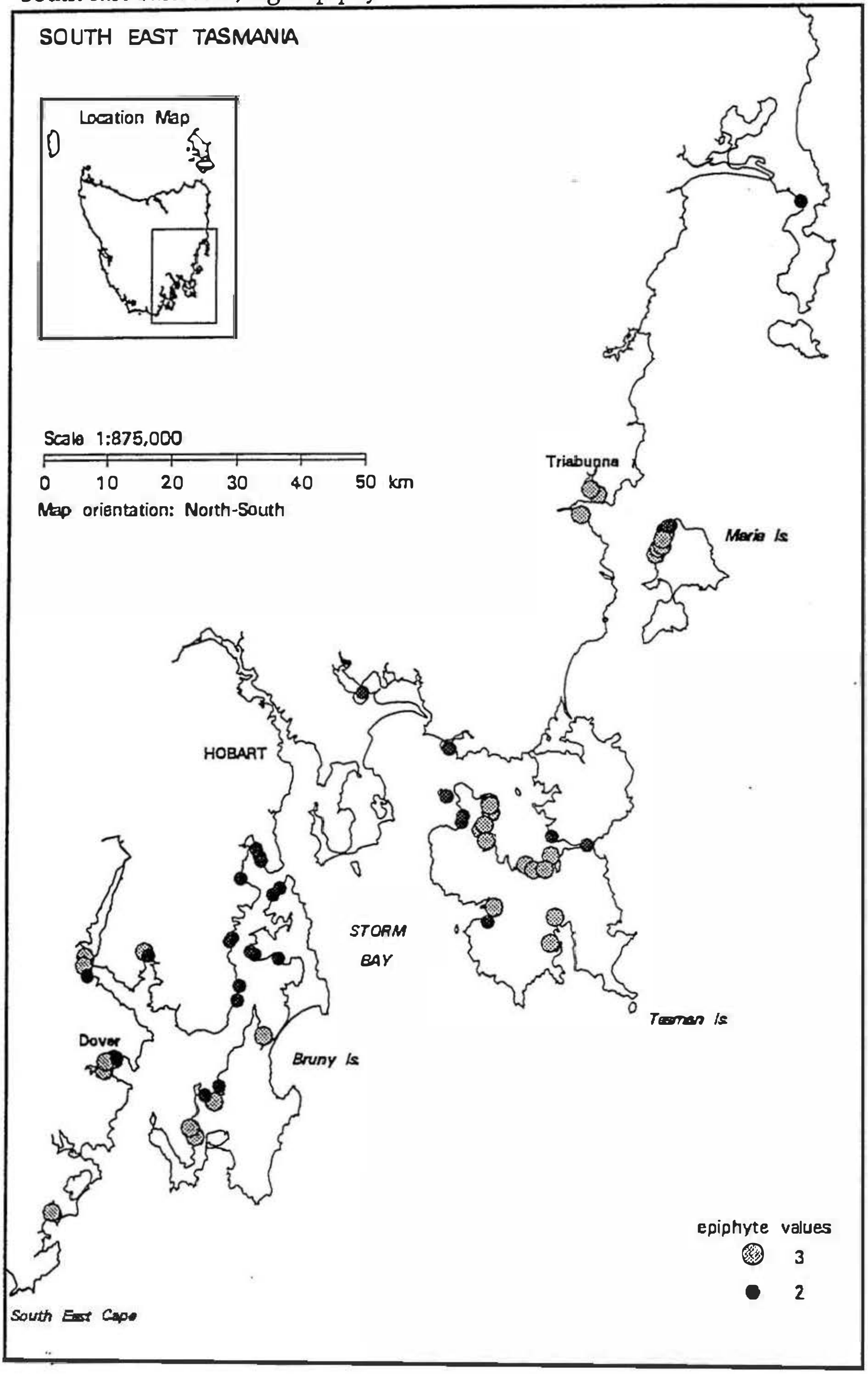
Map 6.16:

South east Tasmania, sample sites with algal epiphyte cover



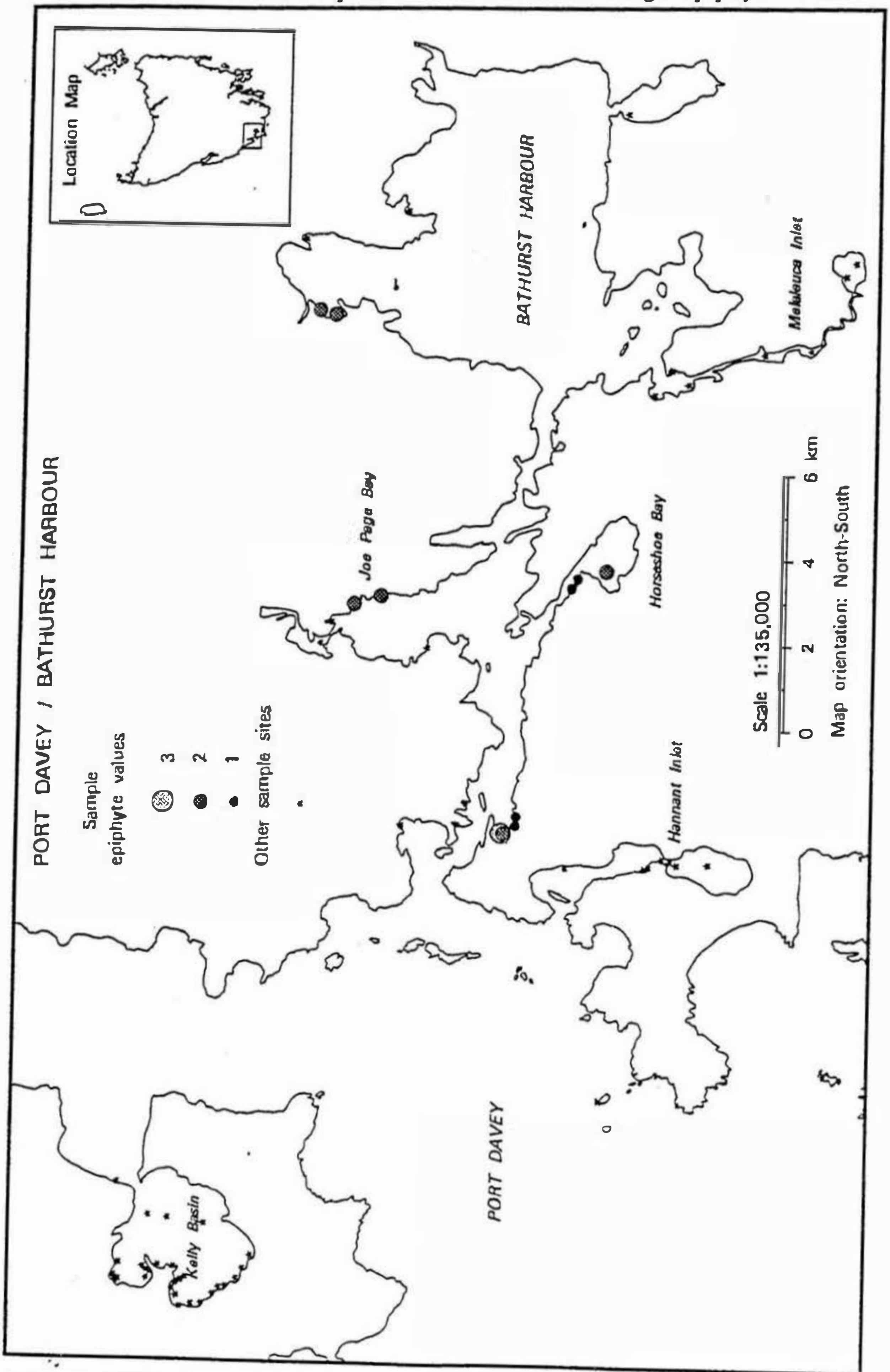
Map 6.17:

South east Tasmania, algal epiphyte values of 2 or 3, & cover of less than 40%



Map 6.18:

South west Tasmania, sample sites with indication of algal epiphyte values



6.2.1.4 Port Davey & Bathurst Harbour

This area in the south west of the state was sampled, but the seagrass beds were not digitally mapped. Map 6.18 indicates the location of 61 sample sites in the region, and those with epiphyte values of 1, 2, and 3. The distribution of seagrasses in the region has been discussed in section 5.2.4. In North Inlet, Horseshoe Bay and Joe Page Bay heavy growths of filamentous green algae were found with the seagrasses. Although not identified, these were different in colour and form to those found in areas of seagrass decline elsewhere in the State.

Only in Schooner Cove, near the ocean entrance to Bathurst Channel, were the algal epiphytes similar to those found, for example, in Port Cygnet or Spring Bay. Of 4 samples in Schooner Cove, 2 had algal epiphyte values of 1, 1 had a value of 2, and 1 a value of 3. These were on *Zostera muelleri* and *Heterozostera tasmanica* beds of very small size. Schooner Cove is a favoured safe anchorage for fishing boats and pleasure craft. The relationship between similar seagrass samples and boat anchorages is discussed in section 6.3.3 below.

6.2.2 Occurence of algal epiphytes on different seagrass species

Although not an indicator of potential seagrass decline, from the data collected on seagrass samples, the relationship between seagrass species and their susceptibility to algal epiphyte growth can be considered (Table 6.2). These figures only serve to illustrate possible trends, since the number of sample sites in a given area is quite arbitrary, and dependant on such factors as remoteness, weather conditions and the vessel used.

Table6.2:
Relationship in samples between species and epiphyte values

Species	Proportion of samples	% of samples affected	Epiphyte value (1)	(2)	(3)	No. of affected sample areas
A. antarctica	17 of 84	20%	14%	6%	0%	4
H. australis	70 of 149	47%	32%	13%	2%	17
H. tasmanica	157 of366	43%	22%	12%	9%	41
P. australis	30 of64	47%	28%	16%	3%	3
Z. muelleri	41 of 120	34%	21%	9%	4%	17

Amphibolis antarctica was sampled with algal epiphytes off Devonport, in the

Tamar, Coles Bay and Adelaide Bay. *Posidonia australis* was affected in the Tamar, Parrys Bay and Adelaide Bay. For *P. australis*, the high number of samples in these three areas compared to other sites inflates the overall percentage of epiphyte affected samples. However, the species is clearly susceptible to algal epiphyte smothering in sheltered habitats in proximity to human development. *A. antarctica* overall has a far lower rate of algal epiphyte presence in samples than other species, perhaps due to its preference for a marine environment.

Halophila australis and *Heterozostera tasmanica* have a high rate of algal epiphyte presence, derived particularly from their broad distribution in the sheltered coastal habitats of the south east, such as Norfolk Bay, the Derwent Estuary and the D'Entrecasteaux Channel. Nutrient inputs into these waters are widespread. *H. tasmanica* is affected in many areas where decline has been described earlier. *Zostera muelleri* is broadly distributed both near development, and more remotely. It is in the former that the 17 epiphyte affected areas are located.

The figures in table 6.2 therefore seem to indicate some relationship between the habitat preferences of each species and its susceptibility to algal epiphyte growth, but a more systematic sampling strategy would be required to clarify this issue.

6.3 Correlation of algal epiphyte occurence and seagrass decline

Since algal epiphytes utilise dissolved nutrients more effectively than seagrasses, high levels of their biomass may be taken to indicate water bodies with higher than natural nutrient levels. These are most likely to occur where nutrients are discharged or run off from sites of human activity.

The hypothesis that algal epiphyte presence in seagrass beds is correlated with seagrass decline has been tested here by comparing the rate of loss of seagrass measured in this study with the frequency of algal epiphyte contamination of samples. 28 sample areas were mapped over time (see Table 6.3). Of these, 2 (57 & 58) were excluded since they are extreme outliers, even though they showed an increase in seagrass cover and had no epiphyte affected samples, which would strengthen the correlation. A further 5 were excluded as no present day samples were collected, and dieback has apparently been 100% (areas 19, 93, 95, 96, 97). Duck Bay was excluded since the water quality has improved in recent years, and, in addition, seagrass sampling was restricted to the eastern half of the bay. Together these factors indicated unreliable epiphyte values, since the sewage treatment plant and municipal disposal area, both possible nutrient sources are sited further west.

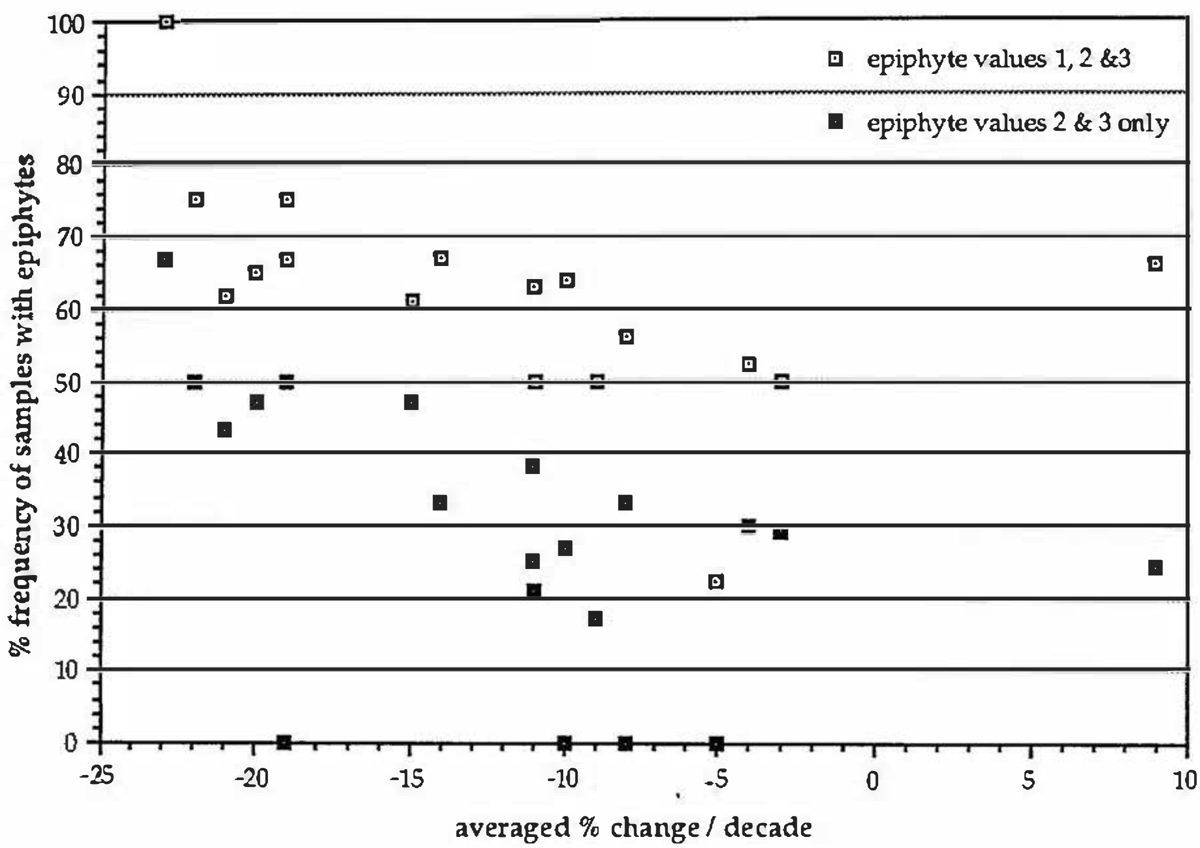
Table 6.3:

Seagrass loss and algal epiphyte presence in mapped sample areas

Area code	Area Name	Coast type	% change per 10 yrs	% samples with epiphytes 1, 2 & 3	% samples with epiphyte 2 & 3
3	Duck Bay	7	-35%	60	0
19	Port Sorell	5	-23%	0	0
21/22	Greens Beach & Port Dalrymple	10, 5	-4%	52	30
43	Georges Bay	5	-11%	50	21
57	Bryans Corner	8	118%	0	0
58	Promise Bay	9	292%	0	0
59	Coles Bay	8	-11%	63	25
63	Mayfield Bay	8	-8%	0	0
65	Little Swanport	5	9%	50	17
67	Oakhampton Bay	8	-10%	0	0
68	Spring Bay	8	-19%	75	50
73	Blackman Bay	7	-3%	50	29
77	Port Arthur (Long Bay)	8	-11%	63	38
78	Port Arthur (Carnarvon Bay)	8	-8%	56	33
79	Wedge Bay & Parsons Bay	8	-10%	64	27
80-82	Sloping Main to Deer Pt.	8, 9	-21%	62	43
83-85	Deer Pt. to Chronicle Pt.	8	-15%	61	47
86/87	Chronicle Pt. to Fulham Pt.	8	-20%	65	47
88	Fulham Pt. to Primrose Pt.	8	-19%	67	0
89	Primrose Pt. to Tiger Head	9	-14%	100	33
90/91	Pittwater	4	-22%	75	50
93	Pipe Clay Lagoon	7	-23%	0	0
95	C. Direction to Gellibrand Pt.	9	-24%	0	0
96	Ralphs Bay (Mortimer Bay)	7	-24%	0	0
97	Ralphs Bay (Rokeby)	7	-24%	0	0
100	North West Bay	8	-9%	66	24
104	Birchs Pt. to Three Hut Pt.	8	-23%	100	67
124	Cloudy Lagoon	4	-5%	22	0

For the 20 areas remaining, the percentage frequency of samples with algal epiphytes was plotted against the averaged seagrass loss per decade (Figure 6.3.). Two sets of samples are represented, firstly all epiphyte affected samples, and secondly those with the higher values 2 and 3, plotted from data in Table 6.3.

Figure 6.3:
Frequency of algal epiphyte affected samples compared with averaged seagrass loss per decade for 20 sample areas



In assessing the strength of the relationship between these two variables, it is important to acknowledge the limitations of the two data sets. The measurement of decline in seagrass cover has been produced from a simple average of the difference between digitised outlines, derived from aerial photographs taken at two points in time from two to four decades apart. The values for algal epiphyte cover are based on the percentage of point samples from a given coastal area that displayed algal epiphyte presence on one day for each area in 1992. Sampling was primarily aimed at ground truthing aerial photographs, and was not structured on a random basis. Furthermore, the numbers of samples in a given area ranged from 4 to 30, an unavoidable variation in the light of sampling constraints.

The correlation coefficient between the two variables was calculated. The correlation coefficient, r, for the relationship between 10 year decline and the percentage of samples with algal epiphyte 1, 2 and 3 is -0.483 (df = 18; r^2 = 0.233), rejecting H_0 at a probability of 0.05. For the subset of algal epiphyte values 2 and 3, r = -0.541 (df = 18; r^2 = 0.292), rejecting H_0 at a probability of 0.02. The relationship is therefore marginally stronger where only heavier algal epiphyte values are used.

Although these results do not explain past seagrass decline, the correlation is significant within the data limitations outlined above, and lends weight to the possibility that decline in these areas is, at least in part, linked to the presence of algal epiphytes in the seagrass beds. If this is true, then it may be inferred that, in those areas where algal epiphytes are present, decline may continue.

6.4 Other impacts on seagrass beds

Various factors with a possible influence on seagrass decline were noted in the course of this study. These were not researched in any great detail, but are commented on here.

6.4.1 Damage by boating activities and infrastructure

6.4.1.1 Moorings

Localised mechanical damage to seagrass beds by mooring chains has been noted elsewhere (Lukatelich *et al.* 1987). Sheltered coastal areas close to centres of population and regions of fishing and recreational boating activity often have a high density of mooring buoys. They also offer good habitat for seagrasses.

Lukatelich and co-workers in the Perth region found that the scouring effect of mooring chains destroys seagrasses in circular patches as vessels swing around in wind changes. The scoured areas were from 3 to 300 m^2. In this study of Tasmanian seagrasses a number of sites were identified on aerial photographs where such damage is clearly evident, and a selection of these are included here to illustrate the problem. No estimates of the extent of damage have been made, but this issue has been raised to confirm that a problem exists.

Plate 11 shows scour patches from the following areas:

(a)	Carnarvon Bay, Port Arthur	(Project 1056 photo 191, 28/1/86)
(b)	Margate, North West Bay	(Project 1026 photo 142, 15/2/85)
(c)	North West Bay marina	(Project 1176 photo 4, 24/11/91)
(d)	Coles Bay	(Project 1184 photo 177, 19/2/92)

Plate 11:

Damage to seagrass beds by mooring chains

Circular scour patches in *Halophila australis* and *Heterozostera tasmanica* bed, Coles Bay, 1992

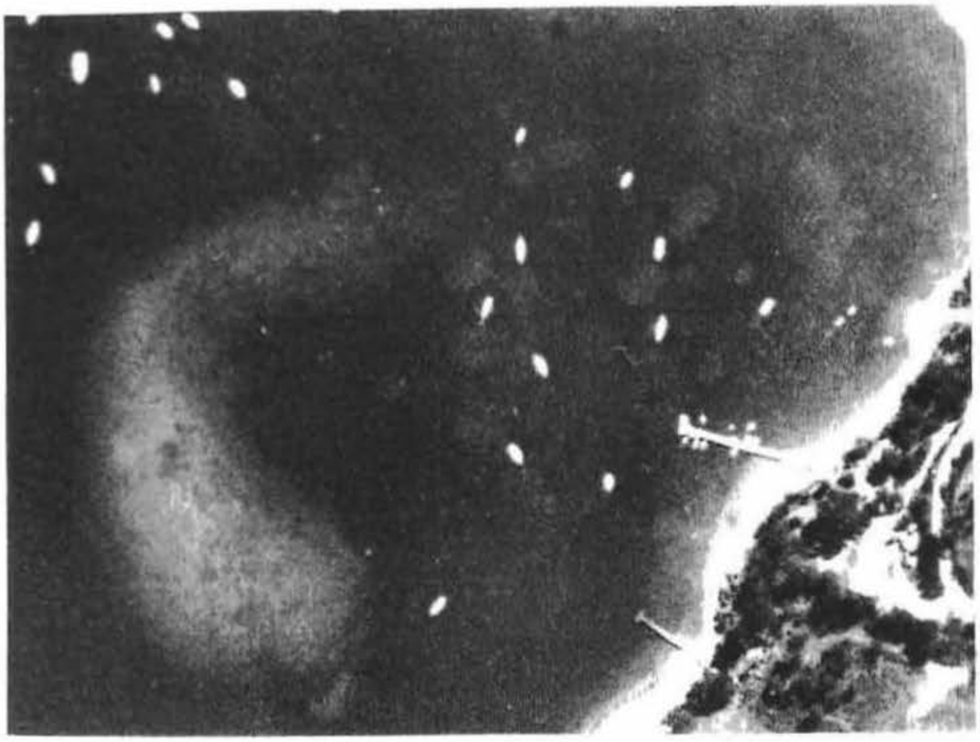
Circular scour patches in *Halophila australis* and *Heterozostera tasmanica* bed, Margate, North West Bay, 1985

Circular scour patches in *H. australis* and *H. tasmanica* bed, North West Bay Marina, 1991

Circular scour patches in *Heterozostera tasmanica* bed, Carnarvon Bay, Port Arthur, 1986

Plate 12:

Damage to seagrass beds by mooring chains in Little Oyster Bay, Kettering



Circular scour patches in *Halophila australis* bed,
Little Oyster Bay, Kettering, 16/2/92

Circular scour patches in *Halophila australis* bed,
Little Oyster Bay, Kettering, 16/3/90

Plate 12 shows scour patches of one area in different years:

(a) Kettering, Little Oyster Bay (Project 1182 photo 196, 16/2/92)
(b) Kettering, Little Oyster Bay (project 1152 photo 142, 16/3/90)

Although the areas of seagrass lost may be small as a proportion of the total, in small bays such as Coles Bay the impact may be more significant, particularly when combined with other adverse pressures. Such scoured areas may lead to undercutting by the erosion of surrounding areas, a loss of detritus and nutrients, impacts on the epiphytic biota and associated food chains, and a greater potential for storm damage to surrounding seagrass beds (Walker *et al.* 1989). Lukatelich *et al.* (1987) suggested that swing moorings in seagrass beds should be replaced where possible by less damaging 'cyclone' moorings, and that areas of coastline with little or no seagrass should be chosen for future boat harbour developments. These ideas should be considered in formulating coastal development policy in Tasmania.

6.4.1.2 Boat movement

Seabed scouring by boat movements has damaged seagrasses in some areas. Examples include damage to *Posidonia australis* beds off Whitemark jetty (map 5.11), bare strips each side of the canal at Dunalley, and long bare channels in the seagrasses amongst the oyster farms in Little Swanport (Map 5.16). Locally, the areas damaged may be comparable to losses from boat moorings, with equivalent secondary effects.

6.4.1.3 Boat effluent discharge

A number of small sheltered inlets used as temporary anchorages were encountered when sampling in otherwise undeveloped areas. These offered suitable habitat for seagrasses, but in some cases had very sparse unhealthy coverage and high levels of algal epiphytes. Three sites are of interest because boating would appear to be the dominant, or only human activity at that site. They include Tinpot Bay and Missionary Bay on the D'Entrecasteaux coast of Bruny Island, and Schooners Cove in Bathurst Channel.

Tinpot Bay had a blanket of undifferentiated filamentous alga smothering a *Heterozostera tasmanica* bed of less than 10% coverage. A part of Missionary Bay identified as a yacht anchorage (CYCT 1987) had heavy algal epiphyte presence amongst a very sparse bed of *Halophila australis* and *Heterozostera tasmanica*. *Zostera muelleri* and *H. tasmanica* beds in Schooner Cove had high algal epiphyte values and sparse seagrass coverage.

It is possible that, at times of heavy usage, food waste and untreated sewage introduce sufficient nutrients to support excessive growth of algal epiphytes. This may subsequently lead to seagrass dieback. Most boating activity takes place in calmer summer months when water temperatures are higher, seas are calm resulting in less flushing of such areas, and growth rates of aquatic vegetation including algae is most rapid.

In other areas of Tasmania this issue may be a contributary factor amongst others to high nutrient levels in seagrass habitats. For example, anchorages at Coles Bay, Carnarvon Bay, Port Cygnet, Mickeys Bay on Bruny Island, Prosser Bay near Orford and Bluff Farm anchorage near Whitemark had high epiphyte values that could be attributed to a number of nutrient sources.

6.4.1.4 Coastal engineering

The construction of training walls in estuaries and dredging activity can change erosion and sedimentation patterns in coastal areas. This may cause direct mechanical damage to seagrass beds, or damage them by smothering or erosion (Parry & Collett 1985). In this Tasmanian survey no examples of dredging damage were encountered, but clear photographic evidence of seagrass loss near Kelso in the Tamar was found after the construction of a training wall (Map 6.1), and a similar development at the mouth of Georges Bay may have lead to changes in substratum levels on the north and south side of the channel where significant losses of *H. tasmanica* and *Z. muelleri* have been recorded (Map 6.5).

6.4.2 *Cygnus atratus* - the Black Swan

The presence of Black Swans is a good indicator that beds of seagrass, usually *Zostera muelleri*, or *ruppia* sp. are below the surface. Some local reports have suggested that seagrasses in some areas have declined inversely to the increase in the population of these birds (J. Thureau, Sunday Tasmanian 16/2/92). Studies in the Port Philip Bay region of Victoria indicate that, although swans eat seagrass, their long term effect on seagrass beds is beneficial, and that adverse impacts are only encoutered where wetland feeding sites are degraded or lost, leading to excessive pressure on seagrasses (Brown 1986).

No evidence of a relationship between swan feeding patterns and seagrass loss can be inferred from this study.

Chapter 7
DISCUSSION

7.1 Management and protection

"Unfortunately management of seagrass areas is not an easy process as it is not confined to managing the meadows themselves. ..... We believe that to successfully manage seagrass beds requires not only controls on waterway and waterside developments, but also a total catchment management plan." (West *et al.* 1989, p. 254)

To avoid further seagrass decline, management options must clearly go beyond giving pristine areas protected status, although this remains a useful tool. It is clear from this study that a significant proportion of the seagrass beds in Tasmania are found in areas close to large concentrations of human population or activity, and that many of these areas have shown some decline. From the perspective of seagrass protection, total catchment management must involve measures addressing all sources of nutrients entering waterways, and any activities that increase the turbidity of water in seagrass habitat.

Past approaches to human waste disposal have left present and future generations with an infrastructure based on a view of waterways as open drains, perennially flushed with sea or river water which dilutes and removes the effluent. Present practices have, on the question of nutrients, improved little.

Current standards for ambient quality for 'coastal waters' receiving sewage discharge in Tasmania place no limit on nutrient levels, biological oxygen demand or faecal coliforms. Standards for 'bays and estuarine waters' are higher, but still place no limits on nutrients. Statewide, 45 sewage treatment plants discharge directly into coastal, bay or estuarine receiving waters. On the evidence of other studies, supported by the findings here, it is argued that significant reductions in nutrient discharges into coastal waters are required through environmental policy and its implementation at all levels if coastal management practices are to reflect the importance of seagrass communities to the ecology of coastal waters. Similarly, land management practices in forestry and agriculture, and engineering works must reflect an understanding of the impact on marine vegetation of increased turbidity and siltation in waterways .

7.1.1 Monitoring

The Tasmanian Department of Environment and Land Management is currently adopting key indicators for monitoring the marine environment. It is uncertain at this point in time whether seagrasses will be monitored. VIMS (1991) supported the inclusion of seagrasses in such a program, and gave recommendations for a suitable monitoring strategy. Such a strategy would include the following:

(1) Monitoring should assess the area and health of seagrass meadows, acquiring data by the analysis of aerial photography with appropriate ground-truthing and detailed survey, assessing meadows for their extent, density, and epiphyte load, and establishing permanent transects in selected areas to monitor minor boundary and depth zonation changes.

(2) The monitoring should initially be annually, and at same time of year. But this should be reviewed after six years, with a subsequent monitoring interval of not greater than 5 years. The sites should be at a number of selected locations (on the Bass Strait coast in the Victorian case).

Permanent transects can be installed by driving a line of star pickets, commonly at 10 m intervals, into the sea bed. Only 300-400 mm of each picket is left exposed to avoid navigation hazard. These are covered with a yellow plastic sheath, and a marker buoy attached to the final picket. The precise position of the transect can be determined, and small changes in seagrass bed boundaries and depth zonation can be simply and accurately measured, and other parameters assessed (H. Kirkman 1991, pers. comm.).

The findings of this study support the implementation of such a program in Tasmania in the immediate future. The program would require sufficient sites to monitor both the range of species and habitats around the State, including adequate control sites in pristine areas to account for natural variation. By employing dedicated aerial photography or aerial video, and installing permanent transects, accurate data would be generated which, with the results of other indicator monitoring, would identify problem areas, and verify the outcomes of water quality improvements.

7.1.2 Protected areas

The four Marine and Estuarine Protected Areas (MEPA) in Tasmania, as previously stated (Section 1.3.2.2), include no significant seagrass communities apart from beds of *Heterozostera tasmanica* off Maria Island. Rationales for the establishment of marine reserves in the State included the protection of representative samples of marine ecosystems, and the recreational, research and educational role that they would play (Kriwoken & Haward 1991).

There is strong justification in extending the network of MEPAs to include representative seagrass communities, since these are important marine ecosystems which are in a state of decline, and of which there is little public awareness. In some cases these may need to be solely seagrass reserves, but more probably would include reef communities and open substratum. These sites could be open to recreational diving and research, but no fishing, gillnetting or collecting should be allowed in order to leave faunal assemblages undisturbed.

The selection criteria for seagrass reserves must enable the inclusion in the reserve system of areas that adequately represent and protect the different seagrass species. This should include not only the range of habitats in which those species are found, but also the faunal assemblages that they support under the influence of different marine provinces around the State. These criteria should include the following:

(1) Where possible, reserves should be continuous with adjoining terrestrial reserves, and/or with catchments that are relatively undisturbed (Amos *et al.* 1993). This includes the need for stringent controls on catchment land use and nutrient inputs, and human activities in the coastal zone that in any way compromise the ecological integrity of the reserved area.

(2) In each region of the State, at least one replicate reserve for each community type should be established. This would be the minimum safeguard against losses by human or natural disaster, such as a storm or oil spill, or the incremental impacts of human activity in adjacent catchments. It also reflects the minimum criteria for adequate reservation adopted for terrestrial plant species by Kirkpatrick *et al.* (1991).

(3) Reserves should be as large as possible, and whilst primarily focussed on the protection of seagrass communities, should include other coastal marine ecosystems with which many associated fauna communicate. In total the MEPA system should include a minimum of 10% of the extent of seagrass communities of each type in the State, in line with the rationale adopted for terrestrial plant communities by, for example, the Forestry Commission of Tasmania for forest protection.

(4) The reserves should have not only a research function, but also an educative role. For this reason it is recommended that at least two areas are declared that are close to the major population centres of Hobart, and the centre of the north coast to serve Launceston and the larger coastal towns.

To satisfy the last criteria, special reserves may need to be selected that fail in one or more of the other three, due to the extent of coastal development and other human impact in these areas.

On a species basis, the following areas would need detailed baseline research, but from observations in this study appear to most closely fit the first three criteria.

Amphibolis antarctica: selected areas in the Furneaux Group, plus
(1) Woolnorth Point to Robbins Island
(7/8) Rocky Cape

	(27)	West sandy Cape to East Sandy Cape
	(29)	Waterhouse Passage
	(58)	Promise Bay, Freycinet Peninsula
	(71)	Maria Island

Halophila australis: sites in the Furneaux Group, and in Norfolk Bay and the D'Entrecasteaux Channel could be suitable, but require further research.

Heterozostera tasmanica:	(1)	Woolnorth to Robbins Island
	(21)	Greens Beach
	(29)	Waterhouse Passage
	(57,58)	Bryans Corner and Promise Bay
	(111)	Southport Lagoon
	(112)	Recherche Bay, southern area
Posidonia australis:	selected areas in the Furneaux Group, plus	
	(1)	Woolnorth to Robbins Island
	(21)	Greens Beach
		Swan Island
Zostera muelleri:	(4a,6a)	East Inlet and West Inlet
	(60)	Swan River
	(111)	Southport Lagoon

The variety *Zostera muelleri sensu stricto* is indirectly protected in the Port Davey/Bathurst Harbour waterways through the management provisions of the World Heritage Area in south west Tasmania.

Only in a small number of these areas do seagrasses indicate little or no signs of impact. Some of these, such as the great expanses of *Posidonia australis* in the north west near Woolnorth (1) are unlikely to suffer degradation from nutrient or sediment increases due to their remoteness and apparent coexistence with current farming practices in the relevant catchments. Similarly, areas of *P. australis* and other species in parts of the Furneaux group and in the north east around Swan Island appear in no danger. Other sites are less secure, being closer to human population centres, and these may be in more urgent need of protection from the impacts of future landuse changes. These include:

East Inlet and West Inlet near Stanley, both good examples of tidal arms with extensive intertidal *Zostera muelleri* beds. They have no protection at present.

Southport Lagoon in the south east. This was not sampled in this study, but apparently has large beds of *Zostera muelleri* and *Heterozostera tasmanica* amongst other vegetation. This is an important wildfowl area, and is currently a State conservation area, the lowest form of reservation demanding no vegetation disturbance. But many off road vehicles do enter the area, and cause fires and dune erosion, thus compromising the water quality. Fishing boats also sometimes enter the lagoon.

Areas satisfying the fourth criteria as reserves suitable for research and educational purposes include Greens Beach already listed above. In addition, Mayfield Bay on the east coast has small shallow *Amphibolis antarctica* beds in a safe swimming area, and, closer to Hobart, the vicinity of Green Head and Sloping Island offers possibilities (*Heterozostera tasmanica*), but sites within Norfolk Bay, or in the D'Entrecasteaux Channel may also be considered (*H. tasmanica* and *Halophila australis*).

Extension of the Maria Island reserve to its original dimensions is also strongly recommended to include the *Amphibolis antarctica* beds and deeper reef communities that were lost to narrow fishing interests.

Outside the MEPA system, all seagrass species could be granted protected status under the *National Parks and Wildlife Regulations* 1971 s 6, which gives powers to prescribe species. This step would raise the issue of possible direct or indirect impacts on seagrass communities by shore and water based development proposals, and perhaps help modify current practices. In specifically protecting seagrass species in this way, benefits would flow on to the wider coastal marine environment.

7.2 In conclusion

The results of this study have shown that, around the Tasmanian coastline seagrass communities dominate extensive areas of shallow, sheltered soft-bottomed habitat. In total, these plants may cover as much as 500 square kilometres. These are, therefore, a very significant component in the ecology of inshore and estuarine waterbodies, and open drainage systems. However, it is also clear that, in many parts of the State, these communities have suffered significant decline, and are showing indications that this decline is a continuing process. The causes of this problem have only superficially been considered in this thesis, and it is likely that a range of factors are involved, both of human and natural origin.

The review of the literature on seagrass ecology and mechanisms of decline included here, including case studies from other parts of Australia, suggests possible reasons for the degraded state of seagrasses in some parts of Tasmania. The two most prominent agents of disturbance cited in other studies are the increase in nutrient levels entering waterways, and increases in turbidity through suspended solids in the water column. Neither factor has been measured here, although the presence of algal epiphytes on seagrasses has been documented. The prominent role of these in seagrass decline is supported by numerous studies. Although relying on qualitative data, a correlation between high epiphyte levels in present seagrass beds and seagrass decline over recent decades has been demonstrated.

Algal epiphytes are only one possible cause, and there may well be other natural agents at work. For example, Larkum and den Hartog (1989) questioned the fitness of seagrasses for a submerged marine existence, but noted that there are many potentially severe natural stresses which they are able to tolerate. These include: wave-action, temperature change, a high-salt environment, nutrient limitation, infection, herbivory, light and shade variation, epiphytes, pressure and anaerobiosis. The synergistic effects of combinations of these and other factors may lead to an increase or decline in seagrasses in an area, independant of any additional factors introduced by human activity.

It has not been possible to differentiate between the natural and human influences on the distribution of seagrasses in Tasmania from the time-restricted sampling and remote sensing basis of this study. However, if nutrient enrichment of coastal waters is the major factor in the loss of seagrass, the implications for the health of the coastal marine environment in Tasmania are important. It can be argued that all the cases of seagrass decline described and mapped in this study, and the epiphyte affected sites indicated in Chapter 6, lie within the sphere of influence of nutrient discharges from one or more of the following: sewage treatment plants, agricultural runoff, intensive animal rearing plants, urban runoff, industrial effluent (e.g. food processing), septic installations especially in coastal shack areas, nutrient input from mariculture activities, leachate from waste disposal sites, and effluent from boats. This is particularly true in the south east of the State.

These widespread nutrient discharges point to the likelihood of ongoing pressure on seagrass beds and the populations of marine fauna species that depend on seagrass communities at some stage of their lifecycle, including some of commercial importance. If this is true, then, by implication, those safeguards currently employed to limit the entry of nutrients and sediments into our waterways are not adequate. Standards often set to protect human health, or to fit within budgetry constraints, are failing to protect the health of the marine environment.

This study has demonstrated that a decline has occurred, and is probably still in progress. It is clear that some research now needs to be focussed on mitigating its causes, so that these vulnerable communities continue to play their essential role in the ecology of Tasmania's inshore coastal waters.

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Appendix I

AERIAL PHOTOGRAPHY DETAILS

(N.B.: B = b &w print; B(C) = b & w print of colour negative; C = colour print)

DATE	FILM No.	PHOTO No.s	RUNS	SCALE	TYPE
1 Woolnorth Pt to Kangaroo Island					
1985	1038	146,166,172,176,196,204	1,1A	42 000	B
3 Duck Bay					
19/2/68	1603	19-22,83,84	15,16	31 680	B
25/3/90	1155	214	3	42 000	B
4a West Inlet					
10/3/92	1190	208	3	42 000	B
6a East Inlet					
10/3/92	1190	208	3	42 000	B
19 Port Sorell					
1946	Beaconsfield K55/30		7,8	15 840	B
21 Badger Head to Friend Pt					
1946	Beaconsfield K55/30		5	15 840	B
22/11/91	1175	76	7	42 000	B(C)
22 Port Dalrymple					
1946	Beaconsfield K55/30		4,5,6	15 840	B
22/11/91	175	76,77	7	42 000	B
7/2 /92	182	18,20,22,24	3	12 500	B(C)
33 Little Mussel Roe Lagoon					
21/2/90	1151	185	2	42 000	B
35 Mussel Roe Lagoon					
21/2 /90	1151	176	2	42 000	B
43 Georges Bay					
16/3/50	St.Helens P.1271		2,3	36 000	B
19/2/92	1184	133,135,138,142	1	20 000	B(C)
57 Bryans Corner (Freycinet Peninsula)					
6/4/49	Swansea	4616,4618	2A	15 840	B
14/11/91	1173	172	1	52 000	B
58 Promise Bay					
16/4/49	Swansea	4627	2A	15 840	B
14/11/91	1173	168,170	1	52 000	B

DATE	FILM No.	PHOTO No.s	RUNS	SCALE	TYPE
59 Coles Bay					
16/4/49	Swansea 4633		2A	15 840	B
19/2/92	1184	175,177,179	1	12 500	B(C)
60 Moulting Lagoon					
11/1/92	1184	193-195,206,207	23,24	45 000	B
62 Swansea to Webber Point					
7/3/92	1185	165,173	2	12 500	B
63 Mayfield Bay					
1/12/48	Swansea 0817		10	15 840	B
11/1/92	1180	8	2	42 000	B
65 Little Swanport					
1947	Swanston			15 840	B
28/7/90	1158		2,4	7 500	B(C)
67 Oakhampton Bay					
1948	Swanston		13	15840	B
25/2/90	1151	228	31	42 000	B
68 Spring Bay					
1948	Swanston		13	15840	B
8/2/66	Prosser 1595	24,71	9,10	31 680	B
2/3/91	1169	52,55,57,59	1,2	12 500	B(C)
69 Prosser Bay					
25/2/90	1151	235	32	42 000	B
71 Maria Island					
15/8/46	Maria		1,2,3	15 840	B
14/1/66	1596	88-91,100-102		31 680	B
25/2/90	1151	233		42 000	B
	1154	32,33,34		42 000	B
73 Blackman Bay					
17/1/48	Sorell K55/83		4,4A,5,6,6A	15840	B
25/2/90	1154	82,83,84	37	42 000	B
77 Port Arthur - Long Bay					
14/3/46	Tasman K55/89		6	15 840	B
8/3/92	1189	18,20	1	12 500	B(C)
78 Port Arthur - Carnarvon Bay					
14/3/46	Tasman K55/89		7,8,9	15 840	B
8/3/92	1189	22,24	1	12 500	B(C)

DATE	FILM No.	PHOTO No.s	RUNS	SCALE	TYPE
79 Wedge Bay (Parsons Bay)					
14/3/46	Tasman K55/89		6,7	15 840	B
7/3/66	1598	110,111,113,160	4,5	15 840	B
27/2/92	1187	201,208	1	12 500	B(C)
80 Sloping Main & Sloping Island					
3/3/66	1598	28,30,60	2,3	15 840	B
25/2/90	1154	96,104	38,39	45 000	B
81 Lime Bay & Monk Bay					
3/3/66	1598	73,128	4,5	15 840	B
25/2/90	1154	94	38	42 000	B
82 Ironstone Point to Deer Point					
3/3/66	1598	120,121,122	5	15 840	B
25/2/90	1154	108,109	39	42 000	B
83 Deer Pt to Sympathy Pt					
3/3/66	1598	152-4,198	6,8	15 840	B
25/2/90	1154	118,119	40	42 000	B
84 Eaglehawk Bay and Little Norfolk Bay					
3/3/66	1598		9,10,11	15 840	B
25/2/90	1154	110,111	39	42 000	B
85 Heather Point to Chronicle Point					
3/3/66	1598	25-31,47-50,102-4	9,10,11	15 840	B
25/2/90	1154	92	38	42 000	B
86 Chronicle Point to Dunbabbin Point					
3/3/66	1598	25-31,47-50	9,10	15 840	B
25/2/90	1154	91	38	42 000	B
87 Dunbabbin Point to Fulham Point					
3/3/66	1598	177-183	8	15 840	B
25/2/90	1154	91,92	38	42 000	B
88 Fulham Point to Primrose Point					
8/4/48	Sorell		6	15 840	B
25/2/90	1154	79	38	42 000	B
89 Primrose Point to Tiger Head					
8/4/48	Sorell		5, 6	15 840	B
18/12/69	F112	171		31 680	B
11/12/91	1176	135, 154	2, 3	42 000	B

DATE	FILM No.	PHOTO No.s	RUNS	SCALE	TYPE
90 Pittwater (North of causeway)					
4/3/46	Hobart	9787,9866-7	2	15 840	B
17/1/48	Sorell	3207, 3209	2	15 840	B
18/12/69	F112	57,58		31 680	B
25/2/90	1154	66		42000	B
91 Pittwater (South of causeway)					
4/3/46	Sorell	3205/14/15/17/19	1	5 840	B
18/12/69	F112	59,60,61		31 680	B
25/2/90	1154	65		42 000	B
93 Pipe Clay Lagoon					
8/1/48	Hobart K55	1645,1647	16	15 840	B
95 Cape Direction to Gellibrand Point					
96 Ralphs Bay (Mortimer Bay)					
8/1/48	Hobart K55		11,13,14	15 840	B
18/12/69	F112			31 680	B
97 Ralphs Bay (Rokeby)					
8/1/48	Hobart K55	1628,1629	15	15 840	B
18/12/69	F112	94		31 680	B
100 North West Bay					
8/1/48	Kingborough		1,3,4	15 840	B
16/2/92	1184	56,58,60,61,62,64		12 500	B(C)
101 Oyster Cove					
16/2/92	1184	196	1	12 500	B(C)
102 Oyster Cove Point to Deadmans Point					
16/2/92	1184	198, 200	1	12 500	B(C)
103 Deadmans Point to Birches Point					
15/12/48	Kingborough		7,7A,8	15 840	B
2/3/65	1519	41,42,72,76	6,7	31 680	B
14/2/90	1150	190 42 000	B		
104 Birches Point to Three Hut Point					
15/12/48	Kingborough		8,8A,9,10,11,11A	15 840	B
2/3/65	1519	41,42,72,76	6,7	31 680	B
14/2/90	1150	183	43	42 000	B
109 Port Esperance					
25/3/92	1191	126, 130	1	24 000	B

DATE	FILM No.	PHOTO No.s	RUNS	SCALE	TYPE
110 Hastings Bay and Southport					
9/3/92	1190	40, 68	46, 47	42 000	B
111 Southport Lagoon					
9/3/92	1190	68	47	42 000	B
112 Recherche Bay					
8/4/91	1171	84, 132	3, 4	5 000	B(C)
113 Dennes Point to Woodcutters Point					
15/2/85	1026	81,82	9	15 000	B
117 Missionary Bay					
15/2/85	1026	73	9	15 000	B
118 Great Bay					
15/2/85	1026	94,95,97	10	15 000	B
119 Isthmus Bay					
15/2/85	1026	21,22,23	8	15 000	B
122 Great Taylor Bay					
14/2/90	1150	45, 46		42 000	B
124 Cloudy Bay Lagoon					
2/3/65	1519	64	6	31 680	B
9/3/92	1190	35, 46		42 000	B
146 Parrys Bay (Whitemark)					
17/3/92	1189	84	P.P.	30 000	C
8/1/91	1163	17,18	3	27000	B
147 Adelaide Bay (Lady Barron)					
17/3/92	1189	76,119	4	30 000	C
8/1/91	1163	36,39,44	1	26 000	B

Appendix II
MODIFIED DOUBLE-SIDED ANCHOR DREDGE

The inclined plane is designed so the dredge will dig into the seagrass bed deeply in one place. It is not towed, but paid out on a warp 5 times the depth, and the boat drifted or moved slowly until the dredge bites. (measurements in millimetres; weight approximately 5 kg)